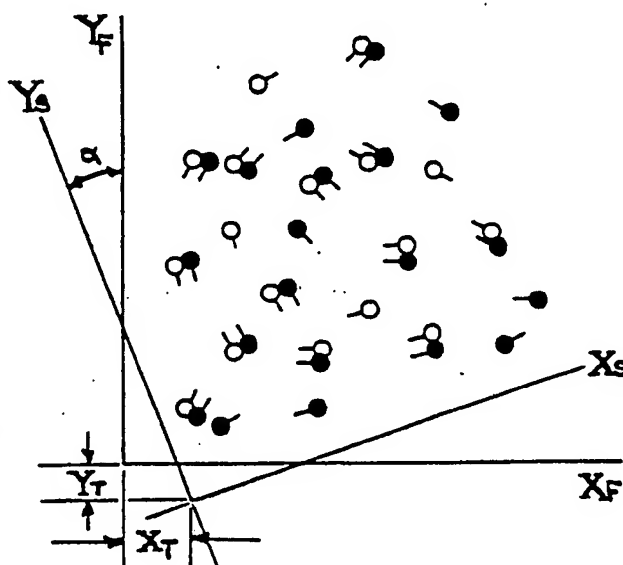## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(54) Title: FINGERPRINT MINUTIAE MATCHER

(57) Abstract

A machine or process for comparing fingerprints based on the correspondence between fingerpring minutiae. The pattern of minutiae in an unknown or search fingerprint is rotated and translated to obtain approximate registration with the pattern of minutiae in a known on file fingerprint. Following rotation and translation, only those search and file fingerprints that exhibit a sufficient number of mating minutiae between the fingerprints are compared further. For each pair of mating search and file minutiae, the neighboring mating minutiae are compared and an individual minutia 'match score' is determined based on the degree of correspondence between the other mating pairs of minutiae within a specified neighborhood of the individual pair of mating search and file minutiae. The individual 'match scores' for each of the mating minutiae are summed to yield a total score that is indicative of the correspondence between the search and the file fingerprints.

SEARCH MINUTIA SUPERIMPOSED ON FILE MINUTIA

FINGERPRINT MINUTIAE MATCHER

BACKGROUND OF THE INVENTION

A fingerprint can be characterized by the locations and angular orientations of the ridge endings and ridge bifurcations within the fingerprint which data are referred to in this specification as "minutiae". Machines for the detection and listing of fingerprint minutiae are described in a number of U.S. Patents, including Nos. 3,611,290; 3,699,419; 4,083,035; and 4,151,512.

This invention pertains to processes and machines for the automatic comparison of one fingerprint, referred to here as the "search" fingerprint with another fingerprint, referred to as the "file" fingerprint, to determine if the two prints were made by the same finger.

A minutia pattern matcher invented by Riganati and Vitols is described in U.S. Patent No. 4,135,147. The present invention is closely related to the minutia pattern matcher invented by Riganati and Vitols. U. S. Patent No. 4,135,147 describes, in some detail, the prior art and the background to which both this invention and the minutiae pattern matcher pertain.

The minutia pattern matcher of Riganati and Vitols generates a "relative information vector" ("RIV") for each minutia in the unidentified ("search") fingerprint, which RIV is a detailed description of a minutia's immediate neighborhood of nearly surrounding minutiae. The matcher compares each RIV in the search print with each RIV in the known ("file") print and generates a match score for each comparison (see Cols. 8-12 of U.S. Patent No. 4,135,147). By means of a histogram, the matcher makes a global comparison of the individual matches and generates a "final score" which indicates, quantitatively, how closely the search print compares with the file print (see Col. 12 of U. S. Patent No. 4,135,147). Because the minutia pattern matcher compares each RIV in the search print with each RIV in the file print, the process involves a significant amount of effort.

The present invention significantly reduces the effort expended in the comparison, first, by performing a preliminary comparison of search and file minutiae on a global basis in order to reject file prints which bear little resemblance to the search print (to give a "quick out") and, second, by, in effect, comparing each search RIV with only a single,

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mating file RIV. The details of the present process also differ from
those of the minutia pattern matcher.

SUMMARY OF THE INVENTION

This invention is a machine or process that compares or "matches"
fingerprint minutia patterns. The result of this matching process is a
match score which is a measure of the similarity of the two minutia
patterns, with a high match score indicating a high degree of similarity.
The machine of this invention is a general purpose computer, such as the
IBM 7090, that has been programmed in accord with this specification.
The inputs to the machine are (1) the minutia data for the fingerprints
being matched (one print is designated the search print, the other the
file print), which minutia data consist of the locations (x,y) and angular
orientations (θ) of the minutiae, and (2) a set of machine operating
parameters. The minutia data are ordered in a θ in a lowest to highest
values of θ. Tables 1(a) and 9(b) show an example of minutia data in
tabular form (the format in which the computer stores and uses the data),
and Figures 1A, B and C are plots of such data.
The object of the invention is to measure the similarity between
two minutia patterns, such as those shown in Figures 1A and 1B. A
high degree of similarity exists between the patterns in Figures 1A and
1B, as is shown in the superimposed patterns of Figure 1C where the
search minutia of Figure 1A have been rotated by an angle α and translated
in X an amount X_T and in Y an amount Y_T, and then superimposed on the
file pattern.
One measure of similarity is the number of corresponding minutiae.
To determine this number, one can think of a small box being drawn
around each search minutia as shown in Figure 2A. If there is a file
minutia within the box which also has the minutia angle close to the
search minutia angle (say, within 25^{0}), then the two minutiae are said
to correspond, or to be mates. Figures 2A, B and C illustrate several
cases of mating, non-mating, and multiple mating minutia pairs. There
are 13 corresponding or mating minutia pairs in Figure 1C. This number of
mating minutiae, designated M_M, is used as a preliminary measure of
similarity.

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If M_M is sufficiently high, a score is computed for each search minutia based on the number of neighboring search minutiae (up to some number such as eight) that also have a mating file minutia, and on the degree of correspondence between the neighboring, mating file and search minutia. The match score for the entire fingerprint is the sum of the scores for each search minutia.

If the number of mating minutiae, M_M, is not greater than some specified threshold, the file print is considered to be unrelated to the search print, and the fingerprints are not compared further.

Table 2 is a listing of all the major steps in the comparison or matching process. A more detailed functional description of each of these steps is given in the following sections.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1A and 1B are examples of search and file minutiae respectively;

Figure 1C shows the search minutiae of Figure 1A rotated and superimposed on the file minutiae in Figure 1B;

Figures 2A, B and C show examples of mating and non-mating pairs of minutiae;

Figure 3 shows the search minutiae of Figure 1A with each minutiae numbered;

Figures 4A and 4B contain a second example of search and file minutia patterns;

Figure 5 is a two-dimensional histogram for the example in Figures 4A and 4B;

Figure 6 is a flow diagram of the logic used to compare the search and file minutiae;

Figure 7 contains an example of overlaid plots of search and file minutiae;

Figure 8 is a logic flow diagram illustrating the detailed logic for processing the NHIT list of Table 8; and

Figure 9 is a flow diagram illustrating the minutia pairing logic.

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DESCRIPTION OF THE PREFERRED EMBODIMENT

1.0 PREPARATION OF SEARCH MINUTIA DATA

In a typical application of the invention, a single search fingerprint is compared against many file fingerprints. Certain computations, involving the initial search minutia data only, are done only once at the beginning of the series of comparisons.

1.1 SORT INTO ANGLE ORDER

To decrease the computation time, the search minutiae are sorted, based on their angle, in ascending order as shown in Table 1. If the minutiae are already sorted with respect to θ, this step is skipped.

1.2 FIND CLOSEST NEIGHBORS

Since the scoring for each pair of mating minutiae is dependent on the number of neighbors that also have mates, the N_N nearest neighbors for each search minutia must be defined. The number N_N is a match parameter selected by the machine operator and is typically chosen to be in the range of 6 to 12. The "nearness" measure is the sum of the absolute values of the differences in the X and Y coordinates between two minutiae. Such a measure is easily computed and results in a diamond shaped neighborhood area. Figure 3 shows the search minutiae of Figure 1A with each minutia numbered. Table 3 lists the nearest eight neighbors for some of the search minutiae. The nearest neighbors for each minutia are determined by computing the distance from each minutia to all other minutiae and selecting the N_N closest minutia as the nearest neighbors.

1.3 ROTATE SEARCH MINUTIAE FOR EACH ANGULAR POSITION

Since the X, Y, θ minutia values for the search and for the file fingerprints initially are not located with respect to a unique coordinate system, it usually is necessary to rotate one of the minutia patterns with respect to the other to properly align the matching fingerprints, as illustrated, for example, in Figure 1C. There appears to be no straightforward method of computing a best rotation based on some criteria such as

a least-squared-error fit. Accordingly, in this process, the search
minutiae are rotated through a series of preselected angles and these
rotated sets of minutiae are stored. In the matching process, each set of
rotated search minutiae are compared with the file print and the set which
gives the best match (as measured by the number of paired minutiae) is
used in computing the match score for the pair of prints being compared.

In the preferred embodiment, a discrete set of rotations, N_R,
spaced 5.6 degrees apart are used in the matching process. A set of
ten such rotations covers a range of ± 28 degrees and normally is sufficient
to allow for variations in fingerprint orientation. The number of rotations,
N_R, is a match parameter specified by the operator, and can be made as
large as desired in order to accommodate larger uncertainties in print
orientation. Since a larger number of rotations would require more
comparisons, it is desirable to use as small a value of N_R as practicable.

Functionally, the rotated X and Y minutia values are computed by
the matrix equation

$$\begin{bmatrix} X_R \\ Y_R \end{bmatrix} = \begin{bmatrix} COS\alpha & SIN\alpha \\ SIN\alpha & COS\alpha \end{bmatrix} \cdot \begin{bmatrix} X_S \\ Y_S \end{bmatrix} \qquad (1)$$

where X_R, Y_R are the rotated minutia values, X_S, Y_S are the initial search
minutia values, and α is the rotation angle. In order to use only
integer computations and to avoid using sine and cosine functions, the
following approximations are used for the sine and cosine computations:

$$COS\alpha = 1 - 32/CDIV(N) \qquad (2)$$

$$SIN\alpha = 32/SDIV(N) \qquad (3)$$

The CDIV(N) and SDIV(N) functions are represented by integer tables
which have values for each N corresponding to discrete values of α.
Values of CDIV(N) and SDIV(N) are computed from the inverse of the above
equations and have the form

$$CDIV(N) = \frac{32}{1 - COS\alpha} \qquad (4)$$

$$SDIV(N) = \frac{32}{SIN\alpha} \qquad (5)$$

where N has values 1, 2, ... N_{RT},

α has values $(-N_{RT}+1)(5.6^O)$, $(-N_{RT}+3)(5.6^O)$, $(-N_{RT}+5)(5.6^O)$,

$$\ldots (-N_{RT}+2N_R-3)(5.6^O), (-N_{RT}+2N_{RT}-1)(5.6^O)$$

and N_{RT} is the total number of rotations permissable and is an even integer.

The values of θ for each rotation can be obtained simply by adding an angle to each θ value equal to the rotation α defined above. This addition, however, is performed later in the matching process, thus avoiding the creation of an additional array of rotated values for θ.

In order to minimize the computational errors in the rotation calculations, the search minutiae are initially centered over the origin. The rotation computations then are performed for the translated data set, and the rotated minutia sets then are retranslated to the first quadrant so that all X and Y values for the minutiae are positive.

2.0 PREPARATION OF FILE MINUTIA DATA.

Very little preparation of the file print minutia data is necessary or desirable since these computations need to be performed for each file fingerprint with which the search print is compared. The file data are arranged in order with respect to θ and the minimum and maximum minutia X and Y values are determined for the file print, but these calculations need be done only once for each file print for instance, at the time the file print data is added to the data base. A simple computation also can be done at the time the file print is added to the data base to determine the quantization parameters for use with the histograms described in the next section.

3.0 PRINT REGISTRATION

Print registration or orientation matching requires the determination of the best angular rotation and the X and Y offsets or translation that are necessary to superimpose the search minutia pattern upon the file minutia pattern. This task is accomplished by constructing for each of the N_R rotations of the search minutia pattern, a two dimensional histogram of the displacements in X and Y needed to overlay each search minutia with each file minutia for which the values of θ differ by less

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than some threshold, which threshold is a matching parameter selected by
the operator. If the computed displacements for a pair of search and file
minutiae are greater than some specified threshold, this minutia pair is
omitted from the histogram. An example of such a pair of minutia would
be one near the top of one print and the other near the bottom of the
other print. Such minutiae would not represent mating pairs. A large
peak in the histogram indicates a large number of mating minutia pairs,
and the coordinates of that peak give the X and Y offsets needed to give
the best line up of the two minutia patterns for a particular angular
rotation.

To illustrate and more precisely describe these operations, consider
the example minutia patterns shown in Figures 4A and 4B, which example
differs from the one shown in Figures 1-3. The search minutia pattern
is one of the rotated sets of search minutia patterns. If the file minutia
pattern is shifted 10 units in X and 10 units in Y (10 is added to each
of the minutia X and Y values), there is almost a perfect correspondence
between the search and file minutia patterns. Table 4 contains a minutia
comparison matrix. This matrix lists the result of comparing each search
minutia (the leftmost column of the matrix) with each file minutia (the
top row of the matrix). The matrix entries show the results of the
comparison. The letter A indicates that the tail angles for the two
minutiae corresponding to that matrix element (e.g., search minutia,
S1, and file minutia F8) differ by more than the allowed amount (30
degrees).

The two numerical entries for each pair of file and search minutia
(e.g., 24, -20 for S2, F1) indicate the increments in X and Y that must
be added to the file minutia data in order to superimpose that file
minutia on top of the search minutia after the centers of the search and
file minutia patterns have been made coincident.

The coordinates for the center of the search print are the average
of the X and Y values respectively for the search minutiae. The Y
coordinates for the center of the file print are the mid-points between
the maximum and minimum values of X and Y respectively for the file
minutiae. The center for each minutia pattern is shown by the + symbol
in Figures 4A and 4B.
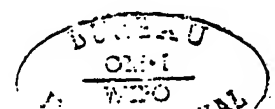
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The coordinate values shown for each minutia in the top row and left
column of the comparison matrix of Table 4 are with respect to the center
of the print. Thus, to compute the translations in X and Y, ΔX and ΔY,
that are required to superimpose two minutiae, such as S2 and F4, the
values of the file minutia are subtracted from the values of the search
minutia, as shown by the equations of Figure 4. For the S2, F4 minutia
pair, these differences are 12 and 10 for X and Y, respectively, as shown
in the F4 column and S2 row of the comparison matrix. The +2 term in the
X translation equation of Figure 4 is necessary to allow for the non-
alignment of the center of the minutia patterns (the coordinates of the
center of the search minutiae are 28, 30 and for the file print center are
30-30 producing a difference in the X coordinates of 2).

The entries of the letter L indicate that the translation required
for the superposition of two minutiae (e.g., S2, F5) exceeds a threshold
which is half of the file minutia pattern width for X and half of the file
minutia pattern height for Y. Both the X and Y translations must be less
than these thresholds to avoid an L entry. The width and height of the
file minutia patterns of Figure 4 are 55 and 50, respectively.

Using the numbers contained in the comparison matrix, a two dimensional
histogram is constructed. Figure 5. shows such a histogram for the example
of Figure 4. Each cell of the histogram corresponds to the translations
in X and Y listed on the top and left edges of the histogram. The number
within each cell indicates the number of minutia pairs that exist for a
given X and Y translation of the search print. The histogram is constructed
by first setting all cells in the histogram to zero and then incrementing
(by 1) each histogram cell that corresponds to the numerical entries in
the comparison matrix of Table 4. Thus, for example, the minutia pair
S2, F3, with a comparison matrix entry of 24, 5 causes the contents of the
(24,25; 5,4) histogram cell to be incremented by one. As can be seen
by an examination of Figures 4 and 5, all of the correct or proper
corresponding minutia pairs (e.g., (S1,F3), (S3,F4) etc.), cause either
the (14,15; 11,10) histogram cell or an adjacent cell to be incremented.

To determine from the histogram the best X,Y translation, a search
is made of the histogram cells to find the cell with the maximum value.
The coordinates of the cell with the maximum value gives the translation
values in X and Y which yield the maximum degree of matching. Because of
the discrete nature of the process, a slight modification of the procedure
is used to avoid edge or boundary problems that produce quantization
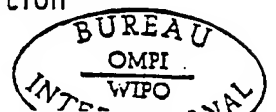
errors. In the example, there actually are eight pairs of corresponding minutiae. Only four of these pairs are counted in the (14,15; 11,10) histogram cell. The counts for the other four pairs appear in the left and top adjacent cells due to slight variations in the spacing between minutiae of the two patterns. To allow for these edge or boundary problems, the maximum count for the histogram is computed based on the sum of the counts for four adjacent cells. Thus, the maximum count for the histogram of Figure 5 is eight, and using the center of the cluster of four cells that gives this maximum, the X and Y translations that best line up the two minutia patterns are (using integer computations) 13 and 11 (assuming an initial alignment of the print centers).

The actual mechanization of this alignment procedure, while functionally the same, is somewhat different computationally from that described in the example. One difference is that a comparison matrix as such is never constructed; the computations are done for each minutia pair comparison by means of two nested DO loops, with the histogram being updated at the completion of each minutia pair computation. The desirability of having the minutiae sorted by angle is apparent from an examination of the comparison matrix of Table 4, since all of the A entries for a given row are in one or two sequential groups which include at least one end of the row. Logic is used in the DO loop computation based on these sequential angle differences to reduce the number of minutia pair computations.

Other computation differences are concerned with the manner in which the boundary problem for the histogram is handled and the construction of the histogram for the matcher where, in effect, four more or less independent computations proceed in parallel.

The minutia pattern line-up or registration process is functionally identical to a two-dimensional discrete pattern correlation process wherein one pattern is placed on top of another, the number of corresponding features are counted, a correlation matrix element is incremented, the pattern is shifted a small increment, and the corresponding features again are counted, etc.

In order to determine the best rotation angle for lining up or registering two prints, histograms as described above are constructed in sequence for each rotation angle. The rotation angle which gives the maximum histogram entry is the best rotation angle. If there is more than one maximum in the histogram (i.e., two or more cells have the same

count which is higher than all others), the coordinates for each maximum
are computed and stored as well as the rotation angles. Such a condition
represents two equally good pattern registrations as determined by the above
registration process. The rest of the matching process is executed for
each of these maximums (up to five) and a match score is computed for
each. The highest resulting match score is taken as the print match
score.

4.0 TEST FOR EARLY OUT

After the two prints have been registered, the maximum histogram
entry, M_M^*, is a measure of how well the minutia patterns match since it
is approximately the number of minutiae that are mates. (This measure
is not exact because of possible double counting - one search minutia might
be "paired" with more than one file minutia by the above process.) A
comparison of M_M^* is made with an early out threshold, E_T. E_T is a
matching parameter that is specified by the operator. The value of E_T
is dependent on the type of search prints used. A typical value for latent
search prints is 15. If $M_M^* < E_T$, a zero match score is assigned, and no
further match computations are performed for these two prints. IF $M_M^* \geq E_T$,
a more refined minutia pairing and scoring procedure is used, as described
in the following sections.

5.0 MINUTIA PAIRING AND SCORING PROCEDURE

The process for minutia pairing and scoring is outlined in Figure 6.
Figure 6 is a flow diagram of the pairing and scoring process. The
various procedures indicated by the blocks in Figure 6 are discussed in
more detail in the following subsections. The process is illustrated
in Figure 7 for which the corresponding minutia data are tabulated in
Table.5. Figure 7 contains an example of the overlaid plots corresponding
to tabular listings of X, Y and θ minutia values and is used to illustrate
the specifics of the process.

5.1 FORMATION OF INITIAL HIT LIST

The first step in the minutia pairing and scoring process is the
formation of a list called the "HIT" list which is a list of the search

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and file minutiae which are near enough to each other to be considered as potential mating pairs of minutiae. Table 6 is a "HIT" list for the example illustrated in Figure 7 and lists for each search minutia those file minutiae which are "close to" it. In order for a file minutia to be considered close to a search minutia, the file X, Y and θ values must satisfy the equations

$$|X_{Si} - X_{Fj}| = \Delta W_{ij}, \quad \Delta X_{ij} \leq E_X$$
$$|Y_{Si} - Y_{Fj}| = \Delta Y_{ij}, \quad \Delta Y_{ij} \leq E_Y \tag{6}$$
$$|\theta_{Si} - \theta_{Fj}| = \Delta\theta_{ij}, \quad \Delta\theta_{ij} \leq E_\theta$$

X_{Si}, X_{Fj}, Y_{Si}, Y_{Fj}, θ_{Si}, and θ_{Fj} represent the ith search and the jth file X, Y, and θ minutia values respectively, and E_X, E_Y and E_θ are the permissable X, Y and θ pairing errors.

For minutia pairs (i,j) which satisfy this criteria, a distance or closeness measure, D_{ij}, is computed as:

$$D_{ij} = \Delta X_{ij} + \Delta Y_{ij} + \Delta\theta_{ij}/S_\theta \tag{7}$$

where S_θ is a quantity used to scale the θ differences to the same range as the X and Y distances and depends on the units used to represent X, Y and θ. For X and Y measured in .008 inch units and θ measured in 5.6 degree units, S_θ would be 4. In addition to satisfying equations (6), in order for a file minutia to be considered close to a search minutia, the following distance relationship must also be satisfied:

$$D_{ij} \leq D_M \tag{8}$$

where D_M is the permissable distance error. This distance measure is also shown for each of the minutia paris listed in Table 6. All file minutia which are "close" to a search minutia (up to a limit of four) are listed in the initial HIT list in ascending order of closeness as measured by D_{ij}, as shown in Table 6.

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5.2 NEIGHBORHOOD HIT LIST

The rest of the minutia pairing and scoring procedure involves
examining all possible search and file minutia combinations and selecting
that combination which tends to maximize the match score under a closeness-
of-fit scoring technique for the neighboring pairs of minutiae. To
determine which neighboring search minutiae also have mating file minutiae,
a list is formed for each mating search minutia, called the "NHIT"
list. An example of an "NHIT" list appears in Tables 7(a)-7(e). The
left-most column of this list is a list of the N closest search minutia
to that search minutia (called here the neighborhood center minutia) for
which the list is formed. The right-hand most column is a list of file
minutia (up to two) which are close to the search minutia listed in the
left-most column of the table. These neighborhood closeness and distance
measures are computed in accord with equations (6), (7) and (8),
although different values of E_X, E_Y, E_θ, S_θ, and D_M (i.e., E_{XN}, E_{YN},
$E_{\theta N}$, $S_{\theta N}$, and D_M) can be specified. That is, the tolerances and scaling
factors can be different for the HIT and NHIT lists. In Table 7(a),
the NHIT list for the search and file pair of minutia (S4,F4) is shown
together with the nearness or closeness measure for the four closest
neighbors to minutia S4 (i.e., S3, S2, S8, S1). This list only includes
the two closest file minutiae for a given search minutia. Duplicate file
minutiae are eliminated from the list according to a set of logic which
first maximizes the number of search minutiae having a mating file minutia,
and then minimizes the distance or nearness measure when two pairs of
minutiae are considered at a time.

.The operation of the logic is illustrated by means of the example
NHIT list of Table 8 (the minutiae of the example are not related to
those of the example in Table 5). The first minutia combination to be
considered by the logic is the S1,F2 combination listed in the first row.
However, an examination of the second row shows that F2 appears in this
row also, and with a smaller distance than in row one. If minutia F2 is
paired with S2 because of the smaller distance, then there is no minutia
to pair with S1. In order to minimize the number of pairings, the selection
is made as shown in the final pairing column of the list. The detailed
logic for processing the NHIT list is shown in the folow chart of Figure
8. In Figure 8:

NB = the number of neighbors for each search minutia

NHIT(I,1) = closest file minutia to the I search minutia in the NHIT list

NHIT(I,2) = distance measure between the I search minutia in the NHIT list and the NHIT (I,1) file minutia

NHIT(i,3) = next closest file minutia to the I search minutia in the NHIT list

NHIT(I,4) = distance measure between the I search minutia in the NHIT list and the NHIT(I,3) file minutia.

Following the logic of Figure 8 and working in a top-to-bottom fashion through the list to eliminate duplicate file minutiae and then selecting the pairing giving the smallest distance measure results in the pairing shown in the "final pairing" column of the list. This logic is not sufficiently complex to always produce an optimum solution since if the file entry for row three would have been (F7,2) instead of (F8,2), the final pairing for the first three rows would have been (F2,5), - , (F7,2) which is not as good as the selection -, (F2,2), (F7,2) for which the combined distance is 4 as compared to 7 for the less complex procedure. The simpler logic, however, is used in order to improve the matching speed since situations requiring the more complex logic are rare.

Once a NHIT list has been edited to eliminate duplicate file minutiae and the resulting, best search-file neighborhood minutia pairings have been determined (according to the above rules), the variance in the fit of the neighboring minutiae is computed. A combined variance over X, Y and θ is computed as:

$$\sigma^2 = \frac{1}{3} \left[\sigma_x^2 + \sigma_y^2 + \sigma_\theta^2/S_\theta \right] \qquad (9)$$

whereas:

$$\sigma_X{}^2 = E\left[(\Delta X - M_{\Delta X})^2\right] = \frac{1}{N_M}\sum_{J=1}^{N_M}(\Delta X_j)^2 - \left[\frac{1}{N_M}\sum_{J=1}^{N_M}\Delta X_j\right]^2$$

$$\sigma_Y{}^2 = E\left[(\Delta Y - M_{\Delta Y})^2\right] = \frac{1}{N_M}\sum_{J=1}^{N_M}(\Delta Y_j)^2 - \left[\frac{1}{N_M}\sum_{J=1}^{N_M}\Delta Y_j\right]^2 \quad (10)$$

$$\sigma_\theta{}^2 = E\left[(\Delta \theta - M_{\Delta \theta})^2\right] = \frac{1}{N_M}\sum_{J=1}^{N_M}(\Delta \theta_j)^2 - \left[\frac{1}{N_M}\sum_{J=1}^{N_M}\Delta \theta_j\right]^2$$

S_θ is a quantity used to scale the $\sigma_\theta{}^2$ values to the same range as $\sigma_X{}^2$ and $\sigma_Y{}^2$. ΔX_u, ΔY_j, $\Delta \theta_j$ are the X, Y and θ differences between neighboring search and file minutiae, and N_M is the number of matching neighbors. Again S_θ is a function of the units used to measure X, Y and θ. For X and Y measured in units of 0.008 inches and θ in units 5.6°, S_θ is in the range of 16-32.

In order to use integer arithmetic, equations (10) are computed using a different scale factor S_σ to scale the computed σ^2 values to appropriate integer values. The value of S_σ depends on the scoring table used and for the scoring table of Table 9, $S_\sigma = 4$. In FORTRAN notation, the equation for determining $\sigma_X{}^2$, equation (10), has the form:

```
IVX   =   ((MXIS - (MXI*MXI)/NMM)*IVARF/NMM
```

where:
                                                                    (11)

$$IVX \quad = \quad \sigma^2{}_X$$

$$MXIS \quad = \quad \sum_{J=1}^{N_M}\Delta X_j{}^2$$

$$MXI \quad = \quad \sum_{J=1}^{N_M}\Delta X_j$$

$$NMM \quad = \quad N_M$$

$$IVARF \quad = \quad S_\sigma$$

Tables 7(b) and 7 (d) show the variance computations for the (S4,F4) and (S4,F2) minutia pairs respectively. In these computations, $S_\sigma = 4$ and $S_\theta = 22.5$. The integer scaled values of σ^2 are indicated by σ_S^2.

Having computed the variance in the neighborhood fit of minutia, the individual minutia score S_{Mi} is determined from a two-dimensional scoring table. An example of such a scoring table is shown in Table 7(e). One dimension of the table is N_M, the number of matching neighbors, and the other is σ_S^2, the combined, scaled variance of the fit. The individual minutia score for the (S4,F4) minutia pair of 0 because σ_S^2 is greater than 14, the largest σ_S^2 entry of the table, while the individual minutia score for the S4,F2 minutia pair is 60 (the fourth row and fourth column entry of Table 7(e)). A careful examination of the minutia patterns of Table 5 shows that the (S4,F2) pairing gives a much better fit for the neighboring minutiae as the σ_S^2 computation for this pairing indicates.

Table 9 is the scoring table used in the preferred embodiment. The table is treated in the computer program as a one-dimensional table for purposes of speed and the indices to the table are computed using the specified minimum and maximum values for N_M and σ_S^2. This procedure, in effect, specifies a score for all of N_M, σ_S^2 space but it does not require an infinite table of scoring values. Thus, using FORTRAN type notation,

$$\text{If } N_M > N_{MX}, \ N_M = N_{MX}$$

$$\text{If } N_M < N_{MN}, \ S_M = 0$$

$$\text{If } \sigma_S^2 > \sigma_{SX}^2, \ S_M = 0 \tag{12}$$

$$\text{If } \sigma_X^2 < \sigma_{SN}^2, \ \sigma_S^2 = \sigma_{SN}^2$$

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where N_{MX}, N_{MN}, σ_{SX}^2, and σ_{SN}^2 are the maximum and minimum allowed values of N_M and σ_S^2 respectively. In Table 9 $N_{MX} = 12$, $N_{MN} = 4$, $\sigma_{SX}^2 = 30$, and $\sigma_{SN}^2 = 1$. Table 9 was developed by intutitive and empirical means so as to give a high score when the search and file fingerprints are similar, and a low score when they are dissimilar.

When the score S_{Mij}, for a given search minutia-file minutia pair (as listed in the initial HIT list), has been determined from its relationship to its closest neighbors, this score is entered in the initial HIT list in place of the distance measure initially computed for this minutia pair. This procedure is repeated until scores have been determined for all minutia pairs defined by the initial HIT list. Table 10(a) is the HIT list for Table 6 with the distance measure replaced by the individual minutia scores. In order to avoid considerable hand computations to provide this example, all of the S_{Mij} entries except for the S_{M44} entries are rough approximations, but are sufficiently representative to illustrate the essential features of the process.

5.3 DETERMINATION OF FINAL HIT LIST AND INDIVIDUAL MINUTIA SCORE

When all of the score entries have been made in the initial HIT list, the file minutia entries for each row are re-ordered to be in decending order based on the score entries, and only the first two entries are retained in the HIT list. The right-most column of the example HIT list of Table 10(a) shows the effect of this or-ordering and truncation.

Using the truncated, score-ordered HIT list, multiple file minutiae are eliminated by selecting that pairing which maximizes the total score when minutia pairings are considered two at a time. The selection process for the example of Table 10 is straightforward- in the right-most column of Table 10(a), the file minutia with the lowest score is always eliminated if multiple entires exist. Those file minutiae to be eliminated are indicated by a star (*) in this table.

A situation not quite so straightforward is shown in Table 11. If the lowest scoring file minutiae are eliminated, there is no mating file minutia for search minutiae S2, S4, S7, and S8. The selection logic considers the pairing for two search minutiae at a time and is such that the combined score for the two minutia pairing is maximized. Figure 9

contains a flow chart of the process. In Figure 9:

> NS = number of search minutia
>
> HIT(i,1) = file minutia number with largest score on ith row of HIT array
>
> HIT(i,2) = score for file minutia of H(i,1)
>
> HIT(i,3) = file minutia number with second highest score on ith row of HIT array
>
> HIT(i,4) = score for file minutia of H(i,3)
>
> A HIT entry of 999 indicates an empty cell or no minutia pairing.

The result of the application of the process shown in Figure 9 to the example of Table 11 is shown in the right-most column of Table 11. The logic is not sufficiently complex to truly maximize the score over all possible pairing combinations. In the example of Table 11, the score would be five points higher if file minutia F9 were paired with search minutia S3 instead of S4 as shown. Such situations requiring more complex logic, however, seem to be very rare, and hence the added logic complexity that would be needed to handle such situations is not included as part of the match procedure.

6.0 FINAL MATCH SCORE

The final match score for the entire print is simply the sum of the match scores for each individual search minutia, as determined from the final HIT list. This is illustrated at the bottom part of Table 10(b).

The invention is mechanized by means of a FORTRAN routine run on any suitable computer system such as the IBM 7090. Appendix I contains a FORTRAN listing of the computer program. Appendix II contains a list of the more significant program variables.

Although the invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of this invention being limited only by the terms of the appended claims.

MINUTIA NO.	MINUTIA COORDINATES		
NO.	X	Y	θ
1	103	13	2
2	18	21	8
3	51	93	40
4	8	29	45
5	30	40	90
6	90	79	130
7	117	43	135
8	116	87	135
9	90	50	160
10	55	30	165
11	120	24	172
12	86	21	174
13	72	98	182
14	101	111	184
15	47	16	187
16	42	99	220
17	23	72	250
18	60	70	295
19	43	52	305
20	70	80	318

a) SEARCH MINUTIA

MINUTIA NO.	MINUTIA COORDINATES		
NO.	X	Y	θ
1	41	118	40
2	34	93	62
3	20	18	67
4	34	36	118
5	75	95	148
6	112	72	170
7	88	69	175
8	78	48	181
9	94	40	185
10	61	36	193
11	73	129	212
12	23	95	250
13	18	63	275
14	33	74	284
15	46	54	320
16	95	91	331
17	58	89	344

TABLE 1   b) FILE MINUTIA

LIST OF BASIC STEPS IN PROCESS

1.0   PREPARE SEARCH MINUTIA DATA

    1.1   Sort Into Angle Order
    1.2   Find Closest Neighbors
    1.3   Rotate Search Minutia For Each Angular Position

2.0   PREPARE FILE MINUTIA DATA

    2.1   Sort Into Angle Order
    2.2   Find Min and Max X and Y Values
    2.3   Compute Quantization Parameters

3.0   PRINT REGISTRATION (FIND BEST ANGLE ORIENTATION AND X, Y OFFSETS
    FOR LINING UP SEARCH AND FILE MINUTIA PATTERNS)

    3.1   For Each Angular Rotation, Build A Two Dimensional
        Histogram of X, Y Translations To Overplay All Possible
        Minutia Pairs
    3.2   Determine X, Y Translations Corresponding To Maximum of
        Histogram
    3.3   Determine Rotation Angle For Maximum of All Histograms
    3.4   Determine Maximum Value of All Histograms M^*_m

4.0   TEST FOR EARLY OUT

    4.1   Compare M^*_m With Threshold E_T
    4.2   IF $M^*_m < E_T$, Assign Zero Match Score, Exit
    4.3   If $M^*_m > E_T$, Proceed

5.0   "ROTATE, TRANSLATE" SEARCH MINUTIA TO BEST MATCH POSITION
    DETERMINE WHICH SEARCH MINUTIA MATE WITH WHICH FILE MINUTIA

6.0   FOR EACH SEARCH MINUTIA WHICH HAS A MATING FILE MINUTIA, TRANSLATE
    SEARCH MINUTIA SO THESE MATING MINUTIA COINCIDE COUNT HOW MANY OF
    N_N CLOSEST NEIGHBORING SEARCH MINUTIA ALSO HAVE A MATING FILE
    MINUTIA N_m COMPUTE THE INDIVIDUAL MINUTIA SCORE. $I_{si} . ASI_{si} = N_M 2$

    6.1   Form Initial "Hit" List
    6.2   Form Neighborhood Hit ("NHIT") List
    6.3   Determine Final Hit List and Individual Minutia Score

7.0   COMPUTE TOTAL FINAL MATCH SCORE $S_M \; ASS_M = \sum\limits_{i=1}^{Ns} I_{si}$

TABLE 2

- 20 -

MINUTIA NO.	8 NEAREST NEIGHBORS
1	11, 12, 7, 9, 15, 10, 6, 8
·2	4, 5, 15, 10, 17, 19, 18, 12
3	16, 13, 20, 18, 6, 19, 17, 14
4	2, 5, 15, 10, 17, 19, 18, 12
5	4, 2, 17, 19, 10, 15, 18, 9
6	20, 13, 8, 14, 9, 18, 3, 7
⋮	

TABLE 3

BUREAU
OMPI

	F1 (-5,25)	F2 (20,10)	F3 (-5,0)	F4 (3,-5)	F5 (-20,-10)	F6 (-5,-15)	F7 (-25,5)	F8 (-28,5)	F9 (-20,-25)	F10 (5,-25)	F11 (27,-10)
S1 (7,10)	14,-15	-11,0	14,10	6,15	L	14,25	▲	▲	▲	▲	▲
S2 (17,5)	24,-20	-1,-5	24,5	12,10	L	24,20	▲	▲	▲	▲	▲
S3 (-8,0)	-5,-25	-26,-10	-1,0	-9,16	14,10	-1,15	▲	▲	▲	▲	▲
S4 (7,-5)	L	-11,-15	14,-5	6,0	L	14,10	▲	▲	▲	▲	▲
S5 (-18,5)	▲	▲	▲	▲	▲	▲	9,0	12,10	▲	▲	▲
S6 (-13,18)	▲	▲	▲	▲	▲	▲	14,13	17,23	▲	▲	▲
S7 (-8,-13)	▲	▲	▲	▲	▲	▲	▲	▲	14,12	-11,12	L
S8 (17,-15)	▲	▲	▲	▲	▲	▲	▲	▲	L	14,10	-8,-3

TABLE 4

SEARCH MINUTIA

NO.	X	Y	θ
1	8	8	25
2	14	21	27
3	10	20	30
4	6	17	32
5	36	10	150
6	31	8	155
7	26	14	160
8	14	14	235
9	28	22	325
10	32	22	330
11	39	22	340

TABLE 5

FILE MINUTIA

NO.	X	Y	θ
1	18	23	25
2	10	19	25
3	14	22	28
4	5	14	30
5	8	9	30
6	12	10	32
7	28	16	150
8	24	12	160
9	39	12	160
10	35	9	162
11	27	8	170
12	12	15	210
13	18	15	230
14	32	24	320
15	36	23	332
16	25	22	342

HIT LIST

SEARCH MINUTIA	CORRESPONDING FILE MINUTIA, DISTANCE
S1	(F5,2), (F6,8), (F4,10)
S2	(F3,1), (F1,6), (F2,6)
S3	(F2,2), (F3,6), (F4,11), (F1,12)
S4	(F4,4), (F2,8), (F5,10), (F3,14)
S5	(F10,3), (F9,7)
S6	(F11,6), (F.10,6)
S7	(F8,4), (F7,6), (F11,9)
S8	(F13,6), (F12,8)
S9	(F16,6), (F14,7), (F15,10)
S10	(F14,4), (F15,5), (F16,9)
S11	(F15,5), (F14,13)

TABLE 6

INITIAL NHIT LIST (S4,F4) PAIRING

DISPLACED SEARCH MINUTIA	CORRESPONDING FILE MINUTIA DISTANCE
S3	(F2,2), (F5,9)
S2	(F2,5), (F3,6)
S8	(F12,7), (F13,9)
S1	(F5,6), (F6,11)

(a)

INITIAL NHIT LIST (S4,F2) PAIRING

DISPLACED SEARCH MINUTIA	CORRESPONDING FILE MINUTIA DISTANCE
S3	(F23,1), (F1,6)
S2	(F1,0), (F3,5)
S8	(F13,2), (F12,10)
S1	(F6,2), (F5,6)

(c)

FINAL NHIT LIST, (S4,F4) PAIRING

SEARCH MINUTIA	FILE MINUTIA	ΔX	ΔY	$\Delta \theta$
S3	F2	1	2	-5
S2	F3	1	4	1
S8	F12	-1	4	-25
S1	F5	1	4	5
	o^2	0.75	0.75	133

$$o_S^2 = 4(0.75) + 4(0.75) + 4(20)/22.5$$
$$= 30$$
$$S_{M44} = 0$$

(b)

FINAL NHIT LIST, (S4,F2) PAIRING

SEARCH MINUTIA	FILE MINUTIA	ΔX	ΔY	$\Delta \theta$
S3	F3	0	0	-2
S2	F1	0	0	-2
S8	F13	0	-1	-5
S1	F6	0	0	7
	o^2	0	0.19	20

$$o_S^2 = 4(0) + 4(0,19) + 4(20)/22.5$$
$$= 4$$
$$S_{M42} = 60$$

(d)

EXAMPLE SCORING TABLE

N \ o_S^2	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2	20	10	5	1	0	0	0	0	0	0	0	0	0	0	0
3	40	20	10	5	3	1	0	0	0	0	0	0	0	0	0
4	150	120	100	80	60	40	20	10	5	3	1	0	0	0	0
5	200	150	120	100	80	60	40	20	10	5	3	1	0	0	0
6	200	200	200	150	120	100	80	60	40	20	10	5	3	1	0

(e)

TABLE 7(a) - 7(e)

DISPLACED SEARCH MINUTIA	CORRESPONDING FILE MINUTIA, DISTANCE	FINAL PAIRING
S1	(F2,5) —	(F2,5)
S2	(F2,2), (F7,5)	(F7,5)
S3	(F8,2) —	(F8,2)
S4	(F8,4), (F9,6)	(F9,6)
S5	(F10,3), (F11,5)	(F10,3)
S6	(F12,3), (F14,5)	F(14,5)
S7	(F14,7) —	—
S8	F(12,1) —	F(12,1)

TABLE 8

SCORING TABLE

NM	4	5	6	7	8	9	10	11	12
1	50	100	120	150	170	200	220	250	250
2	30	60	100	120	150	180	200	220	250
3	20	40	70	110	140	150	180	210	240
4	10	20	60	100	120	140	160	200	220
5	8	16	40	70	100	110	150	190	200
6	5	10	20	40	80	100	130	170	200
7	3	8	16	32	64	90	110	160	180
8	2	6	12	24	48	80	100	150	170
9	1	5	10	20	40	70	100	140	160
10	0	3	6	12	24	50	90	130	150
11	0	2	5	10	20	40	80	120	150
12	0	1	5	10	20	40	80	110	140
13	0	0	4	8	16	32	64	100	120
14	0	0	3	6	12	24	48	100	120
15	0	0	2	4	8	16	32	70	100
16	0	0	1	3	6	12	24	50	90
17	0	0	0	2	4	8	16	40	80
18	0	0	0	1	3	6	12	30	70
19	0	0	0	0	2	4	8	20	60
20	0	0	0	0	1	3	6	10	40
21	0	0	0	0	0	2	4	8	30
22	0	0	0	0	0	1	3	6	20
23	0	0	0	0	0	0	2	4	10
24	0	0	0	0	0	0	1	3	8
25	0	0	0	0	0	0	0	2	6
26	0	0	0	0	0	0	0	1	4
27	0	0	0	0	0	0	0	0	3
28	0	0	0	0	0	0	0	0	2
29	0	0	0	0	0	0	0	0	1
30	0	0	0	0	0	0	0	0	0

TABLE 9

SEARCH MINUTIA	CORRESPONDING FILE MINUTIA INDIVIDUAL MINUTIA SCORES	CORRESPONDING FILE MINUTIA AFTER SCORE ORDERING AND TRUNCATION
S1	(F5,3), (F6,100), (F4,0)	(F6,100), (F5,3)
S2	(F3,10), (F1,80), (F2,1)	(F1,80), (F3,10)*
S3	(F2,3), (F3,100), (F4,0), (F1,0)	(F3,100), (F2,3)*
S4	(F4,0), (F2,60), (F5,0) (F3,0)	(F2,60), (F4,0)
S5	(F10,10), (F9,20)	(F9,20), (F10,10)*
S6	(F11,20), (F10,80)	(F10,80), (F11,20)
S7	(F8,3), (F7,60), (F11,0)	(F7,60), (F8,3)
S8	(F13,100), (F12,3)	(F13,100), (F12,3)
S9	(F16,3), (F14,40), (F15,0)	(F14,40) (F16,3)
S10	(F14,5), (F15,60), (F16,0)	(F15,60), (F14,5)*
S11	(F15,3), (F14,10)	(F14,10)*, (F15,3)*

*Eliminated Minutia

(a) Intermediate HIT List

SEARCH MINUTIA	SELECTED FILE MINUTIA AND SCORE
S1	(F6,100)
S2	(F1,80)
S3	(F3,100)
S4	(F2,60)
S5	(F9,20)
S6	(F10,80)
S7	(F7,60)
S8	(F13,100)
S9	(F14,40)
S10	(F15,60)
S11	

Match Score = 100 + 80 + 100 + 60 + 20 + 80 + 60
            + 100 + 40 + 60
          = 700

(b) Final HIT List

TABLE 10

SEARCH MINUTIA	CORRESPONDING FILE MINUTIA AFTER SCORE ORDERING AND TRUNCATION	FINAL PAIRING AND SCORE
S1	(F3,40)*, (F7,35)	(F7,35)
S2	(F3,20)	(F3,20)
S3	(F9,20)*, (F11,10)*	—
S4	(F9,15)	(F9,15)
S5	(F11,50)	(F11,50)
S6	(F15,60), F(18,30)	(F15,60)
S7	(F15,10)*	—
S8	(F15,5)*	—
S9	(F21,30), (F23,15)	(F21,30)
S10	(F21,25)*, (F26,20)	(F26,20)
S11	(F31,30)*, (F32,20)	(F32,20)
S12	(F31,20), (F33,5)	(F31,20)

* ELIMINATED MINUTIA

TABLE II

APPENDIX I   ECLIPSE FORTRAN 5, VERSION 4.00

```
 1:        SUBROUTINE MATCHP
 2:        OVERLAY OVMAT
 3: C
 4: C      R40 MATCH PROGRAM (MATCHP): CALLS ASORT   DATA GENERAL   11/78
 5: C
 6:        PARAMETER ID1=204, ID4=204, ID3=204, ID5=20, ID6=12
 7:        COMPILER STATIC
 8:        COMMON/ARRAY/F, COUNT,SCORET,IXMIN,IXMAX,TXMIN,IYMAX
 9:        COMMON/PLOTAG/PA,IJS,XOFS,YOFS,IPAAR,PAA,AVX,AVY
10:        COMMON/ARGS/LATID,ISCDA,NP,P,IFCDA,NF,ISCOR,IFLAG,PCN
11:        COMMON/MATGP/IPAR
12:        INTEGER P(3*ID4),COUNT(2500),F(3*ID3),PA(ID5*ID4),NBR(ID6*ID4)
13:       *,SUMX,SUMY,AVX,AVY,SDIV(32),CDIV(32),NPRS(33),SCORET(16,10)
14:       *,RIV(23),NPOS(5),NMAX(5) HIT(ID4),PA (ID4),S(ID5),SS(ID5),NHIT(ID4)
15:       *,NP,NF,ISCOR,ISCOA(24),IFCDA(16),IPAR(256),ISCIVR(500)
16:       *,XOF,YOF,DPX,DPY,PX,PY,PXS,PYS,PCN(9),LATID(7)
17:       *,DELTH,DELX,DX,ERAA,ERAM,DDX,XOFS,YOFS,PXLX,PYLY,ISTAB(512)
18:       *,ASFP,ERAB,ASFN,ASFS
19:        EQUIVALENCE (ISTAB(21),ISCTVR(1)), (COUNT(750),HIT(1))
20:       *,(COUNT(630),NHIT(1)), (S(1),PA(1)), (COUNT(1), SS91))
21:       *,(IPAR(26),IEOT), (IPAR(28),MXNBL), (IPAR(29),NAT)
22:       *,(IPAR(30),ERAA), (IPAR(31),ERAM), (IPAR(32),DELX), (IPAR(33),DX)
23:       *,(IPAR(34),NXMAX), (IPAR(35),NYMAX), (IPAR(36),IETP), (IPAR(37),IETPN)
24:       *,(IPAR(38),DDX), (IPAR(44),IOFLAG), (IPAP(61),ASFP), (IPAR(62),ERAB)
25:       *,(IPAR(63),ASFN), (IPAR(64),ASFS), (IPAR(135),JSMIN), (IPAR(136),IVARF)
26:       *,(IPAR(137),IVARMX), (IPAR(138),JSXMX), (IPAR(139),IVARMN)
27: C
28:        DATA SDIV/-32,-32,-33,-34,-35,-37,-40,-43,-48,-54,-62,-75,-95
29:       * -132,-218,-652,652,218,132,95,75,62,54,48,43,40,37,35,34,33,32,32/
30:        DATA CDIV/34,38,42,48,56,66,79,97,124,163,225,333,547,1068,2957,26556,
31:       * 26556,2957,1068,547,333,225,163,124,97,79,66,56,48,42,38,34/
32: C
33: C**    PREPARE LATENT DATA
34: C
35:        DELTH = 4
36:        IF(NAT .GT. 32) NAT = 32
37:        NPK = NP+NP+4
```

```
38:        IF(NAT*NPK .GT. ID5*ID4) NAT = ID5*ID4/NPK
39:        IF (IFLAG.EQ.1) GO TO 65
40:     C
41:     C  OPEN AND READ FILE CONTAINING SCORING TABLE DATA
42:     C
```

```
43:       OPEN 0,"R40STA",ERR=8030,ATT="C",LEN=512,REC=2
44:       CALL RDBLK(0,0,ISTAR,2,IER)
45:       CLOSE 0
46:       GO TO 8030
47: 8020  TYPE '<CR>AMATCHP* R40STA FILE DOES NOT EXIST'
48:       ISCOR = 0
49:       RETURN
50: 8030  CONTINUE
51:       NRIV = MXRHL
52:       IF(NRIV .GE. NP) NRIV = NP-1
53: C
54: C     SORT INTO ANGLE ORDER
55: C
56:       IRA = ERAA + DELTH * NAT/2
57:       CALL ASORT(IRA,NP,MPT,P)
58: C
59: C     COMPUTE AVERAGE X AND Y
60: C
61:       NP3 = NP*3
62:       NPCO = NP3
63:       SUMX = 0
64:       SUMY = 0
65:       DO 15 I = 1,NP3,3
66:       SUMX = SUMX + S(I)
67: 15    SUMY = SUMY + S(I+1)
68:       AVX = SUMX/NP
69:       AVY = SUMY/NP
70: C
71: C     CENTER LATENT AROUND ORIGIN
72: C
73:       DO 25 I = 1,NPCD,3
74:       SS(I) = S(I) - AVX
75:       SS(I+1) = S(I+1) - AVY
76: 25    SS(I+2) = S(I+2)
```

```
77:  C
78:  C       FIND CLOSEST NEIGHBORS
79:  C
80:        NRIVS = NRIV+1
81:        NN = NP * 3
82:        IT=0
83:        DO 400 I = 1,NN,3
84:        DO 380 L = 1,NRIVS
85:        NARS(L) = 0
86:  380   RIV(L) = 32767
87:        PX = SS(I)
88:        PY = SS(I+1)
```

```
        DO 750 J = 1,NN,3
        IDX = IABS(PX-SS(J))
        IDY = IABS(PY-SS(J+1))
        IR = IDX + IDY
        IF(IR .GT. IPAR(19)) GO TO 750
        IF (IR.GT.RIV(1)) GO TO 750
        DO 620 K = 2,NRIVS
        IF (IR.GT.RIV(K)) GO TO 650
        RIV(K-1) = RIV(K)
620     NBRS(K-1) = NBRS(K)
        K = NRIVS+ 1
650     RIV(K-1) = IR
        NBRS(K-1) = J/3 +1
750     CONTINUE
        IEND = NRIV
760     ITMP = 0
        DO 770 L=2,IEND
        IF(NBRS( L).GT.NBRS( L-1)) GO TO 770
        ITMP = NBRS(L)
        NBRS( L) = NBRS( L-1)
        NBRS( L-1) = ITMP
770     CONTINUE
        IF (ITMP.EQ.0) GO TO 799
        IEND = IEND - 1
        IF (IEND.GT.1) GO TO 760
799     DO 700 L=1,NRIV
        IT = IT + 1
780     NHR(IT) = NBRS(L)
800     CONTINUE
C
C       ROTATE LATENT FOR EACH ANGULAR POSITION
```

```
120:        C
121:              NP2 = NP+NP
122:              NP2CD = NP2
123:              JA = (32-NAT)/2 +1
124:              JB = (32+NAT)/2
125:              KM = -1
126:              DO 30 L =1,NPCD,3
127:              KM = KM + 2
128:              PX = 3S(L)
129:              PXS = 32*PX
130:              PY = 3S(L+1)
131:              PYS = 32*PY
132:              KK = KM
133:              DO 40 N=JA,JB
134:              PA(KK) = PX -(PXS/CDIV(N))-(PYS/SDIV(N))
```

```
135:      PA(KK+1) = (PXS/SDIV(N)) + PY = (PYS/CDIV(N))
136:  40  KK = KK+NP2CD
137:  30  CONTINUE
138:      KKX = KK
139:      JF = -SS(3)
140:      IF(JF .LT. 0) JF = 0
141:      LAMIN = JF+(NAT/2)*DELTH - DELTH/2
142:      K = 0
143:      DO 90 I = 1,NP
144:      K = K+3
145:  90  PAA(I) = SS(K) + JF
146:      IFLAG = 1
147:  65  CONTINUE
148:  C
149:  C**  PREPARE FILE DATA
150:  C
151:      NF3 = NF*3
152:  C
153:  C    COMPUTE QUANTIZATION PARAMETERS
154:  C
155:      NX = MINO((IXMAX-IXMIN)/DELX,NXMAX)
156:      IF(NX.EQ.0) NX=1
```

```
157:        NY = MINO((IYMAX-IYMIN)/DELX,NYMAX)
158:        IF(NY.EQ.0) NY=1
159:        ICXF = (IXMAX+IXMIN)/2
160:        ICYF = (IYMAX+IYMIN)/2
161:        JFXMIN = ICXF - DELX*NX/2
162:        JFYMIN = ICYF - DELX*NY/2
163:        NX1 = NX+2
164:        NY1 = NY+2
165:        NXT1 = NX1*NY1
166:        LX = NX*DELX/2
167:        LY = NY*DELX/2
168:        NP8 = 8*NP
169:        NB4 = NHIV*4
170:   C
171:   C    START OF BASIC MATCH ALGORITHM
172:   C
173:   C    FIRST, FIND THE BEST X,Y OFFSETS AND ANGLE ORIENTATIONS FOR
174:   C    CENTERING THE LATENT PRINT OVER THE FILE PRINT
175:   C
176:   C    COMPUTE SEARCH POSITION LIMITS
177:   C
178:        DO 3 I = 1,NXT1
179:   3    COUNT(I) = 0
180:        IANS = 2
```

```
181:      MMAX = 0
182:      II = -1-NP2CD
183:      IANGM = -DELTH
184: C
185: C     COUNT HITS FOR EACH ANGULAR POSITION
186: C
187:      DO 500 NANGLE = 1,NAT
188:      IANGM = IANGM + DELTH
189:      NJ = 1
190:      II = II + NP2CD
191:      IABIAS = -256-LAMIN+IANGM
192:      DO 300 IBA = 1,2
193:      IABIAS = IABIAS + 256
194:      IJ = II
195:      DO 300 I = 1,NP
196:      IJ = IJ + 2
197:      PX = PA(IJ) + ICXF
198:      PY = PA(IJ+1) + ICYF
199:      PXLX = PX - LX
200:      PYLY = PY - LY
201:      IANG = PAA(I) + IABIAS
202:      N = NJ
203:      DO 275 J = N,NF3,3
204:      IF (IABS(F(J+2) -IANG).GT.ERAA) GO TO 260
205:      IF(IABS(F(J)-PX) .GE. LX) GO TO 275
206:      IF(IABS(F(J+1)-PY) .GE. LY) GO TO 275
207:      KST = ((F(J)-PXLX)/DELX)*NY1 + (F(J+1)-PYLY)/DELX + 1
208:      COUNT(KST) = COUNT(KST) + 1
```

```
209:        COUNT(KST+NY1) = COUNT(KST+NY1) + 1
210:        KST = KST + 1
211:        COUNT(KST) = COUNT(KST) + 1
212:        COUNT(KST+NY1) = COUNT(KST+NY1) + 1
213:        GO TO 275
214:  260   IF (F(J+2).GT.IANG)GO TO 300
215:        NJ = J
216:  275   CONTINUE
217:  300   CONTINUE
218:  C
219:  C     FIND COORDINATES OF MAXIMUM HIT COUNT
220:  C
221:        DO 400 I = 1,NXT1
222:        NSS = COUNT(I)
223:        COUNT(I) = 0
224:        IF (NSS.LT.IANG) GO TO 400
225:        IF (NSS.EQ.IANG) GO TO 399
226:        MMAX=1
```

```
227:        IANS = N99
228:        NPOS(MMAX) = I
229:        NMAX(MMAX) = NANGLE
230:        GO TO 400
231: 399    MMAX = MMAX + 1
232:        IF (MMAX.GT.5) MMAX = 5
233:        NPOS(MMAX) = I
234:        NMAX(MMAX) = NANGLE
235: 400    CONTINUE
236: 500    CONTINUE
237: C
238: C  SECOND, MOVE THE LATENT PRINT AND FIND WHICH OF THE LATENT
239: C     MINUTIAE MATCH AND RECORD THIS IN THE HIT ARRAY.
240: C
241:        ISCOR9 = 0
242:        IF(IAN9 .LT. IEOT) GO TO 992
243:        DO 990 JZ = 1,MMAX
244: C
245: C    FIND THE POSITION OFFSETS
246: C
247:        IN = NPOS(JZ)/NY1
248:        JN = NPOS(JZ) - NY1*IN - 1
```

```
249:        IF (JN.GT.0) GO TO 601
250:        JN = NY
251:        IN = IN - 1
252:  601   CONTINUE
253:        NMAZ = NMAX(JZ)
254:        IJ = NP2CD*(NMAZ-1)
255:        XOF = IN * DELX + JFXMIN
256:        YOF = JN * DELX + JFYMIN
257:        DO 122 I = 1,NP8
258:  122   HIT(I) = 9999
259:        NJ = 1
260:        NANG = (NMAZ-1)*DELTH
261:        IABIAS = -256 - LAMIN + NANG
262:        DO 290 IBA = 1,2
263:        IABIAS = IABIAS + 256
264:        DO 290 I = 1,NP
265:        IH = 8*I-7
266:  278   K = IJ + I + I -1
267:  C
268:  C     TRANSLATE LATENT TO NEW POSITION
269:  C
270:        PX = PA(K) + XOF
271:        PY = PA(K+1) + YOF
272:        IANG = PAA(I) + IABIAS
```

```
      N = NJ
      IF(N.GE. NF3) GO TO 292
C
C     IDENTIFY HITS
C
      DO 280 J = N,NF3,3
      IEA = IABS(F(J+2) - IANG)
      IF(IEA .GT. ERAM) GO TO 279
      IEX = IABS(F(J) - PX)
      IF(IEX.GT. DX) GO TO 280
      IEY = IABS(F(J+1) - PY)
      IF(IEY .GT. DX) GO TO 280
      IET = IEA/ASFP + IEX + IEY
      IF(IET .GT. IETP) GO TO 280
      JH = 6
      IF(HIT(IH+JH+1) .LE. IET) GO TO 2786
      HIT(IH+JH+1) = IET
      HIT(IH+JH) = J/3 + 1
2783  JH = JH-2
      IF(JH .LT. 0) GO TO 2786
      IF(HIT(IH+JH+3) .GE. HIT(IH+JH+1)) GO TO 2786
      ITJ = HIT(IH+JH)
```

```
295:         IT2 = HIT(IH+JH+1)
296:         HIT(IH+JH) = HIT(IH+JH+2)
297:         HIT(IH+JH+1) = HIT(IH+JH+3)
298:         HIT(IH+JH+2) = IT1
299:         HIT(IH+JH+3) = IT2
300:         GO TO 2783
301:   2786 CONTINUE
302:         GO TO 280
303:    279 IF (F(J+2).GT.IANG) GO TO 290
304:         NJ = J
305:    280 CONTINUE
306:    290 CONTINUE
307:    292 CONTINUE
308: C
309: C     THIRD, FOR EACH LATENT MINUTIAE WHICH IS A HIT, MOVE THE LATENT
310: C     PRINT SO THAT THE MATCHING MINUTIAE COINCIDE AND THEN TEST TO
311: C     SEE HOW MANY OF THE CLOSEST LATENT NEIGHBORS ARE ALSO A HIT.
312: C
313:         NBRI = -NRIV
314:         DO 898 LM = 1,NP
315:         NBRI = NBRI + NRIV
316:         DO 895 LM1 = 1,4
317:         IS = 8*(LM-1) + 2*(LM1-1) + 1
318:         IF(HIT(IS).EQ.9999) GO TO 898
```

```
319:      JF4 = HIT(IS)
320:      JJ = (HIT(IS)-1)*3+1
321:      KK = IJ+LM+LM-1
322:  C
323:  C   COMPUTE OFFSETS TO OVERLAY LATENT AND FILE MINUTIAE
324:  C
325:      UPX = F(JJ) - PA(KK)
326:      DPY = F(JJ+1) - PA(KK+1)
327:      NJ = 1
328:      DO 810 LL = 1,NH4
329:  810 NHIT(LL) = 0
330:      IABIAS = -256 - LA4IN + NANG
331:      DO 850 KZ = 1,2
332:      IABIAS = IABIAS + 256
333:  C
334:  C   FIND HITS FOR CLOSEST NEIGHBORS
335:  C
336:      DO 850 K = 1,NRIV
337:      KI = NBR(NBRI+K)
338:      IF(KI .EQ. 0) GO TO 850
339:      IK = KI+KI-1+IJ
340:      PX = PA(IK) + DPX
```

```
341:      PY = PA(IK+1) + DPY
342:      IANG = PAA(KI) + IABIAS
343:      DO 845 JK=1,8,2
344:      JSP = 8*(KI-1) + JK
345:      J = IAND(HIT(JSP),377K)
346:      IF(J .EU. 9999) GO TO 850
347:      IF(J .EU. JFM) GO TO 845
348:      J = (J-1)*3 + 1
349:      IEA = IABS(F(J+2) - IANG)
350:      IF(IEA .GT. ERAB) GO TO 845
351:      IEX = IABS(F(J) - PX)
352:      IF(IEX .GT. DDX) GO TO 845
353:      IEY = IABS(F(J+1) - PY)
354:      IF(IEY .GT. DDX) GO TO 845
355:      IET = IEX+IEY+IEA/ASFN
356:      IF(IET .GT. IETPN) GO TO 845
357:      IH = 4*K - 3
358:      IF(NHIT(IH) .EQ. 0) GO TO 835
359:      IF(NHIT(IH+2) .NE. 0) GO TO 825
360:      IF(NHIT(IH+1) .LE. IET) GO TO 830
361: 820  NHIT(IH+2) = NHIT(IH)
362:      NHIT(IH+3) = NHIT(IH+1)
363:      GO TO 835
364: 825  IF(IET .GE. NHIT(IH+3)) GO TO 845
```

```
365:         IF(IET .LT. NHIT(IH+1)) GO TO 820
366:  830    IH = IH+2
367:  835    NHIT(IH) = J
360:         NHIT(IH+1) = IET
369:  845    CONTINUE
370:  850    CONTINUE
371:  852    CONTINUE
372: C
373: C       ELIMINATE DUPLICATE FILE MINUTIA, SELECT BEST NEIGHBOR PAIRING
374: C
375:         DO 870 I = 1,NB4,4
376:         IF(NHIT(I) .EQ. 0) GO TO 870
377:  855    IFM = NHIT(I)
370:         J = I
379:  858    J = J+4
380:         IF(J .GT. NB4) GO TO 868
381:         IF(NHIT(J) .EQ. 0) GO TO 858
382:         IF(NHIT(J) .EQ. IFM) GO TO 860
383:         IF(NHIT(J+2) .NE. IFM) GO TO 858      ! I1 = J2,J1 .NE. 0
394:         NHIT(J+2) = 0
385:         NHIT(J+3) = 0
386:         GO TO 858
387:  860    IF(NHIT(I+2) .NE. 0) GO TO 865       ! I1 = J1
388:         IF(NHIT(J+2) .NE. 0) GO TO 864       ! I1=J1, I2 = 0
389:         IF(NHIT(I+1) .LT. NHIT(J+1)) GO TO 862  ! I1=J1, I2=0, J2=0
390:         NHIT(I) = 0                          ! I1=J1 I2=0 J2=0, SJ1 .LE. SI1
391:         NHIT(I+1) = 0
392:         GO TO 870
```

```
393:     862  NHIT(J) = 0
394:          NHIT(J+1) = 0
395:          GO TO 858
396:     864  NHIT(J) = NHIT(J+2)
397:          NHIT(J+1) = NHIT(J+3)
398:          NHIT(J+2) = 0
399:          NHIT(J+3) = 0
400:          GO TO 858
401:     865  IF(NHIT(J+2) .EQ. 0) GO TO 866       ! IT=J1,I2.NE.0
402:          IF(NHIT(I+1) .LE. NHIT(J+1)) GO TO 864 ! I1=J1,I2.NE.0,J2.NE.0
403:     866  NHIT(I) = NHIT(I+2)                   ! I1=J1,(S.NE.0/J2=0 .OR. J2 .NE. 0, SI1 .GT.
404:          NHIT(I+1) = NHIT(I+3)
405:          NHIT(I+2) = 0
406:          NHIT(I+3) = 0
407:          GO TO 855
408:     868  NHIT(I+2) = 0                        ! II SELECTED
409:          NHIT(I+3) = 0
410:     870  CONTINUE
```

```
411:  C
412:  C   FIND SCORE FOR NEIGHBORS BASED ON VARIANCE OF FIT
413:  C
414:
415:        MXI = 0
416:        MYI = 0
417:        MII = U
418:        MXIS = 0
419:        MYIS = 0
420:        MIIS = 0
421:        IABIAS = -LAMIN+NANG
422:        NMM = 0
423:        K = 0
424:        DO 880 I = 1,NB4,4
425:        K = K+1
426:        IF(NHIT(I) .EQ. 0) GO TO 880
427:        NMM = NMM + 1
428:        J = NHIT(I)
429:        KI = NBR(NBRI+K)
430:        IF(KI .EQ. 0) GO TO 880
431:        IK = KI +KI - 1 +IJ
432:        ID = PA(IK) + DPX - F(J)
           MXI = MXI + ID
```

```
433:     MXIS = MXIS+ID*ID
434:     ID = PA(IK+1) + OPY - F(J+1)
435:     MYI = MYI + ID
436:     MYIS = MYIS + ID*ID
437:     ID = PAA(KI) + IAHIA3 - F(J+2)
438:     IF(IABS(ID) .GT. 127) ID = ID + 256
439:     MTI = MTI+ID
440:     MTIS = MTIS + ID*ID
441: 880 CONTINUE
442:     J3X = NMM - J3MIN + 1
443:     IF(J3X .GT. JSXMX) JSX = JSXMX
444:     IF(J3X .GE. 1) GO TO 885
445:     IT9X = 99
446:     ISCORV = 0
447:     ITSXS = 0
448:     GO TO 890
449: 885 IVX = ((MXIS - (MXI*MXI)/NMM)*IVARF)/NMM
450:     IVY = ((MYIS - (MYI*MYI)/N44)*IVARF)/NMM
451:     IVT = ((MTIS - (MTI*MTI)/N4M)*IVARF)/(NMM*ASF9*ASF9)
452:     IT9X = (IVX+IVY+IVT)/3
453:     IT9X = IT9X - IVAR4N
454:     IF(ITSX .GT. IVARMX) ITSX = IVARMX
455:     IF(IT9X .LT. 1) ITSX = 1
456:     IXJV = (J3X-1)*IVAR4X+IT9X
```

```
571:        ISCORV = ISCTVR(IXJV)
580:    890 HIT(I3+1) = ISCORV
590:    895 CONTINUE
600:    896 CONTINUE
610:  C
620:  C   ORDER HIT ARRAY ENTRIES BASED ON SCORE
630:  C
640:        DO 920 I = 1,NP6,8
650:        MX = -5
660:        MX2 = -10
670:        DO 910 J = 1,8,2
680:        IF(HIT(I+J) .EQ. 9999) GO TO 915
690:        IF(HIT(I+J) .LE. MX) GO TO 905
700:        MX2 = MX
710:        MX2N = MXN
720:        MX = HIT(J+1)
730:        MXN = HIT(J+I-1)
740:        GO TO 910
750:    905 IF(HIT(J+I) .LE. MX2) GO TO 910
760:        MX2 = HIT(J+I)
770:        MX2N = HIT(J+I-1)
780:    910 CONTINUE
790:    915 IF(MX .LT. 0) GO TO 920
800:        HIT(I) = MXN
810:        HIT(I+1) = MX
820:        IF(MX2 .LT. 0) GO TO 920
830:        HIT(I+2) = MX2N
840:        HIT(I+3) = MX2
```

```
 920  CONTINUE
C
C        SELECT LARGEST SCORE FROM HIT LIST MULTIPLE ENTRIES
C
      DO 960 I = 1,NP8,8
      IF(HIT(I) .EQ. 9999) GO TO 960
 925  IFM = IAND(HIT(I),377K)
      J = I
 930  J = J+8
      IF(J .GT. NP8) GO TO 960              ; I .NE. 9999, J.NE. 9999
      IF(HIT(J) .EQ. 9999) GO TO 930
      IF(IAND(HIT(J),377K) .EQ. IFM) GO TO 935    ; I1 .NE. J1
      IF(IAND(HIT(J+2),377K) .NE. IFM) GO TO 930  ; I1 .NE. J1, J2 = x I1
      HIT(J+2) = 9999                       ; I1 .NE. J1
      HIT(J+3) = 9999
      GO TO 930
 935  IF(HIT(I+2) .NE. 9999) GO TO 948      ; I1 = J1
      IF(HIT(J+2) .NE. 9999) GO TO 945      ; I1 = J1,I2=9999
```

```
503:      937 IF(HIT(I+1) .GT. HIT(J+1)) GO TO 940    ; I1=J1,I2=9999,J2=9999
504:      937 HIT(I) = 9999
505:          HIT(I+1) = 9999
506:          GO TO 460
507:      940 HIT(J) = 9999                           ; I1=J1,I2=9999,/I2=9999,SI1.GT.SJ1 .I
508:          GO TO 930
509:
510:      945 IF(HIT(J+1) .GE. HIT(I+1) + HIT(J+3)) GO TO 937 ; I1=J1,I2=9999,J2.NE.9999
511:      946 HIT(J) = HIT(J+2)                       ;I1=J1,J2.NE.9999,/I2=9999,SJ1.LT.SI1.
512:          HIT(J+1) = HIT(J+3)                      ; I2.NE.9999, SI1.GT.SJ1+SI2
513:          HIT(J+2) = 9999
514:          HIT(J+3) = 9999
515:          GO TO 930
516:      948 IF(HIT(J+2) .EG. 9999) GO TO 950        ; I1=J1,I2.NE.9999
517:          IF(HIT(I+1) .GT. HIT(J+1)+HIT(I+3)) GO TO 946 ;I1=J1,I2.NE.9999,J2.NE.9999
518:          GO TO 952                               ;I1=J1,I2.NE.9999,J2.NE.9999,SJ1.LT.!
519:      950 IF(HIT(I+1) .GT. HIT(I+2) + HIT(I+3)) GO TO 940 ;I1=J1,I3.NE.9999,J2=9999
520:      952 HIT(I) = HIT(I+2)                       ;I1=J1,I2.NE.9999,SI1.L1.SJ
521:          HIT(I+1) = HIT(I+3)                      ;    J2.NE.9999, SI1.LT.SI2+SJ1
522:          HIT(I+2) = 9999
523:          HIT(I+3) = 9999
524:          GO TO 925
525:      960 CONTINUE
526:      C
```

	ATTRIBUTES		POSITION	SIZE
-- ARRAY --				
F	INTEGER ARRAY		0	612.
COUNT	INTEGER ARRAY		1144	2500.
SS	INTEGER ARRAY		1144	20.
NHIT	INTEGER ARRAY		2331	204.
HIT	INTEGER ARRAY		2521	204.
SCORET	INTEGER ARRAY		6050	160.
IXMIN	INTEGER		6310	
IXMAX	INTEGER		6311	
IYMIN	INTEGER		6312	
IYMAX	INTEGER		6313	
-- PLOTAG --				
PA	INTEGER ARRAY		0	4080.
S	INTEGER ARRAY		0	20.
IJS	INTEGER		7760	
XOFS	INTEGER		7761	
YOFS	INTEGER		7762	
IPAAB	INTEGER		7763	
PAA	INTEGER ARRAY		7764	204.
AVX	INTEGER		10300	
AVY	INTEGER		10301	
-- ARGS --				
LATID	INTEGER ARRAY		0	7.
ISCOA	INTEGER ARRAY		7	24.
NP	INTEGER		37	
P	INTEGER ARRAY		40	612.
IFCOA	INTEGER ARRAY		1204	16.
NF	INTEGER		1224	
ISCOR	INTEGER		1225	
IFLAG	INTEGER		1226	
PCN	INTEGER ARRAY		1227	9.
-- MATGP --				

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IPAR	INTEGER ARRAY	0	256.
IVARMN	INTEGER	212	
JSXMX	INTEGER	211	
IVARMX	INTEGER	210	
IVARF	INTEGER	207	
JSMIN	INTEGER	206	
ASFS	INTEGER	77	
ASFN	INTEGER	76	
ERAB	INTEGER	75	
ASFP	INTEGER	74	
IOFLAG	INTEGER	53	
DDX	INTEGER	45	
IETPN	INTEGER	44	
IETP	INTEGER	43	
NYMAX	INTEGER	42	
NXMAX	INTEGER	41	
DX	INTEGER	40	
DELX	INTEGER	37	
ERAM	INTEGER	36	
ERAA	INTEGER	35	
NAT	INTEGER	34	
MXNBL	INTEGER	33	
IEOT	INTEGER	31	

--- STATIC VARIABLES ---

NBR	INTEGER ARRAY	0	2448.
SUMX	INTEGER	4620	
SUMY	INTEGER	4621	
SDIV	INTEGER ARRAY	4622	32.
CDIV	INTEGER ARRAY	4662	32.
NBRS	INTEGER ARRAY	4722	33.
RIV	INTEGER ARRAY	4763	23.
NPOS	INTEGER ARRAY	5012	5.
NMAX	INTEGER ARRAY	5017	5.
ISCTVR	INTEGER ARRAY	5050	500.
ISTAB	INTEGER ARRAY	5024	512.
XOF	INTEGER	6034	
YOF	INTEGER	6035	
DPX	INTEGER	6036	
DPY	INTEGER	6037	
PX	INTEGER	6040	
PY	INTEGER	6041	
PXS	INTEGER	6042	
PYS	INTEGER	6043	

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DELTH	INTEGER	6044
PXLX	INTEGER	6045
PYLY	INTEGER	6046
I	INTEGER	6047
NP3	INTEGER	6050
NPCD	INTEGER	6051
NN	INTEGER	6052
L	INTEGER	6053
NRIVS	INTEGER	6054
J	INTEGER	6055
K	INTEGER	6056
IEND	INTEGER	6057
NRIV	INTEGER	6060
IT	INTEGER	6061
N	INTEGER	6062
JA	INTEGER	6063
JB	INTEGER	6064
KK	INTEGER	6065
NXT1	INTEGER	6066
NANGLE	INTEGER	6067
IBA	INTEGER	6070
NF3	INTEGER	6071
KST	INTEGER	6072
NY1	INTEGER	6073
MMAX	INTEGER	6074
JZ	INTEGER	6075
NP8	INTEGER	6076
IH	INTEGER	6077
JH	INTEGER	6100
LM	INTEGER	6101
LM1	INTEGER	6102
LL	INTEGER	6103
NB4	INTEGER	6104
KZ	INTEGER	6105
JK	INTEGER	6106
IS	INTEGER	6107
NPK	INTEGER	6110
IER	INTEGER	6111
IRA	INTEGER	6112
MPT	INTEGER	6113
IDX	INTEGER	6114
IDY	INTEGER	6115
IR	INTEGER	6116
ITMP	INTEGER	6117
NP2	INTEGER	6120
NP2CD	INTEGER	6121

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KM	INTEGER	6122
KKX	INTEGER	6123
JF	INTEGER	6124
LAMIN	INTEGER	6125
NX	INTEGER	6126
NY	INTEGER	6127
ICXF	INTEGER	6130
ICYF	INTEGER	6131
JFXMIN	INTEGER	6132
JFYMIN	INTEGER	6133
NX1	INTEGER	6134
LX	INTEGER	6135
LY	INTEGER	6136
IANS	INTEGER	6137
II	INTEGER	6140
IANGM	INTEGER	6141
NJ	INTEGER	6142
IABIAS	INTEGER	6143
IJ	INTEGER	6144
IANG	INTEGER	6145
NSS	INTEGER	6146
ISCORS	INTEGER	6147
IN	INTEGER	6150
JN	INTEGER	6151
NMAZ	INTEGER	6152
NANG	INTEGER	6153.
IEA	INTEGER	6154
IEX	INTEGER	6155
IEY	INTEGER	6156
IET	INTEGER	6157
IT1	INTEGER	6160
IT2	INTEGER	6161
NBRI	INTEGER	6162
JFM	INTEGER	6163
JJ	INTEGER	6164
KI	INTEGER	6165
IK	INTEGER	6166
JSP	INTEGER	6167
IFM	INTEGER	6170
MXI	INTEGER	6171
MYI	INTEGER	6172
MT1	INTEGER	6173
MXIS	INTEGER	6174
MYIS	INTEGER	6175
MTIS	INTEGER	6176
NMM	INTEGER	6177

ID	INTEGER	6200
J3X	INTEGER	6201
IT3X	INTEGER	6202
ISCORV	INTEGER	6203
ITSXS	INTEGER	6204
IVX	INTEGER	6205
IVY	INTEGER	6206
IVT	INTEGER	6207
IXJV	INTEGER	6210
MX	INTEGER	6211
MX2	INTEGER	6212
MX2N	INTEGER	6213
MXN	INTEGER	6214
IPSINC	INTEGER	6215

-- EXTERNAL SUBPROGRAMS --

```
.ONCE    .DPSH    .DATI    .IERR    .ILEN
.IREC    .IATT    .FOPE    RDBLK    .FCLO
.ITYP    .FWRS    .TYP     ASORT    MINO
```

REFERENCES

IDENTIFIER	REFERENCES
ASFN	18, 26, 355
ASFP	18, 26, 285
ASFS	18, 26, 451
ASORT	57
AVX	18, 9, 68, 74
AVY	18, 9, 69, 75
CDIV	18, 31, 134, 135
COUNT	18, 8, 26, 179, 208, 209, 211, 212, 222, 223
DDX	18, 26, 352, 354
DELTH	18, 35, 56, 141, 183, 188, 260
DELX	18, 26, 155, 157, 161, 162, 166, 167, 207, 255, 256
DPX	18, 325, 340, 431
DPY	18, 326, 341, 434
DX	18, 26, 282, 284
ERAA	18, 26, 56, 204
ERAB	18, 26, 350
ERAM	18, 26, 280
F	18, 8, 204, 205, 206, 207, 214, 279, 281, 283, 303, 325, 326, 349, 351, 353, 431, 434, 437
HIT	18, 26, 258, 288, 289, 290, 293, 294, 295, 296, 297, 298, 299, 318, 319, 320, 345, 458, 468, 469, 472, 473, 475, 476, 477, 480, 481, 483, 484, 490, 491, 495, 496, 497, 498, 499, 501, 502, 503, 504, 505, 507, 508, 510, 511, 512, 513, 514, 516, 517, 519, 520, 521, 522, 523, 531, 532

	65	66	57	75	74	75	76	83	87	8R	117	143	145	178
IABIAS	191	179	195	201	217	221	222	223	224	233	235	257	258	264
IAÑG	201	265	266	272	306	375	376	377	378	387	349	390	391	402
IArGM	183	403	404	405	406	408	409	410	423	425	427	441	464	469
IANS	180	469	472	473	475	476	477	480	461	443	484	445	489	490
IBA	192	491	492	501	503	504	505	510	517	519	520	521	522	524
ICXF	159	525	530	531	532	536								
ICYF	160	193	201	261	263	272	330	332	342	420	437			
IO	431	204	214	272	279	303	342	349						
ID1	6	148	191	227	242									
ID3	6	224	225	306										
ID4	6	217	262											
ID5	6	161	197											
ID6	6	162	198											
		432	433	454	435	436	437	438	439	440				

Name	References
IDX	90
IDY	91, 92, 92
IEA	279, 280, 285, 349, 350, 355
IEND	103, 105, 110, 112, 113
IEOT	26, 242
IER	44
IET	285, 286, 286, 289, 355, 356, 360, 364, 365, 368
IETP	26, 286
IETPN	24, 356
IEX	241, 202, 285, 351, 352, 355
IEY	283, 284, 285, 353, 354, 355
IFCDA	1A, 10
IFLAG	10, 39, 146
IFM	377, 382, 383, 491, 496, 497
I4	265, 288, 249, 290, 293, 294, 295, 296, 297, 298, 299, 357, 35A, 359, 360, 361, 362, 364, 365, 366, 367, 368
I1	182, 190, 194
IJ	194, 196, 197, 19A, 254, 321, 339, 430
IJ3	9
IK	339, 340, 341, 430, 431, 434
IN	247, 248, 251, 255
IOFLAG	26
IPAAB	9
IPAR	1A, 11, 26, 93
IPSINC	533, 534
IR	92, 93, 94, 96, 100
IJ4	54, 57
IS	317, 31A, 319, 320, 45A

```
ISCDA    1A   10
ISCOR    1B   10
ISCOR9   241  537  4A   529  533  535  537  536  541
ISCORV   446  457  45A  541  534  535
ISCTVR   1B   26   457  532
ISTAB    1B   26   44
IT       82   115  116
IT1      294  294
IT2      295  299
ITMP     104  107  109  111
ITSX     445  452  453  454  455  454
IT3XS    447
IVARF    26   449  450  451
IVARMN   26   453  453
IVARMX   24   454  456
IVT      451  452  452
IVX      449  452  452
IVY      450  452
```

1

Symbol	References
JV	456, 457
MAX	8, 155, 159
MIN	8, 155, 159
MAX	8, 157, 160
MIN	8, 157, 160
	89, 90, 91, 101, 102, 203, 204, 205, 206, 207, 214, 215, 216, 278
A	123, 279, 281, 283, 290, 303, 304, 305, 345, 346, 347, 348, 349, 351
B	124, 353, 367, 378, 379, 380, 381, 382, 383, 384, 385, 388, 389, 393
F	139, 394, 396, 397, 398, 399, 401, 402, 427, 431, 434, 437, 467, 468
FM	319, 469, 472, 473, 475, 476, 477, 478, 492, 493, 494, 495, 496, 497
FXMIN	161, 498, 499, 502, 503, 507, 508, 510, 511, 512, 513, 514, 516, 517
FYMIN	162, 519
H	287, 288, 289, 290, 291, 292, 293, 294, 296, 297, 298, 299
J	320, 325, 326
K	343, 344, 369
N	248, 249, 250, 253, 256
SMIN	26
SP	344, 345
SX	442, 443, 443, 444, 456
SXMX	26, 133, 133, 136, 140, 141, 145, 247
Z	95, 96, 97, 98, 99, 100, 101, 142, 144, 145, 243, 253, 266, 270, 271, 336, 539

Identifier	Values
KI	327, 337, 357, 370, 422, 424, 428, 430, 437
KK	132, 338, 339, 342, 344, 428, 429
KKX	134, 135, 136, 138, 138, 321, 325, 326
KM	125, 127, 132, 210, 211, 212
KST	207, 208, 209
KZ	331, 370
L	84, 85, 86, 105, 106, 107, 108, 109, 110, 114, 116, 126, 128, 130
LAMIN	141, 137, 191, 261, 330, 420
LATID	18, 10
LL	328, 329
LM	314, 317, 321, 460
LMI	316, 317, 459
LX	166, 199, 205
LY	167, 200, 206
MINO	155, 157
MMAX	181, 226, 228, 229, 231, 232, 233, 234, 243

Label														
MPT	57													
MTI	416	419	439	440	451	451								
MTIS	419	440	451	451										
MX	465	469	470	472	479	481								
MX2	466	470	475	476	482	484								
MX2N	471	477	483											
MXI	414	432	449											
MXIS	417	433	449											
MXN	471	473	480											
MXNBL	26	51												
MYI	415	435	450											
MYIS	418	436	450											
N	133	134	135	136	202	203	273	274	278					
NANG	260	261	330	420										
NANGLE	187	229	234	236										
NAT	26	36	38	56	123	124	141	187	236					
NB4	169	328	329	375	380	410	423	441						
NBR	18	116	337	428										
NBRI	313	315	337	428										
NBRS	18	95	98	101	106	107	108	109	116					
NF	18	10	151											
NF3	151	203	216	274	278	305								
NHIT	18	26	329	358	359	360	361	362	364	365	367	368	376	377
		341	382	383	388	389	390	391	393	394				
		397	398	399	401	402	403	404	405	406	408	409	425	396
														427
NJ	189	202	215	259	273	304	327							
N4AX	18	229	234	253										
N4AZ	253	254	260											

NMW	421	426	442	449	450	451								
NN	81	83	89	102	117	61								
NP	18	10	37	52	57	460	68	69	81	121	143	145	168	195
NP2	121	217	264	306	314									
NP2CD	122	122	182	190	254									
NP3	61	136	65	67										
NP8	168	257	258	464	485	489	494	525	530	536				
NPCD	62	73	76	126	137									
NPK	37	38												
NPOS	18	228	233	247	248	116	169	313	315	336	370			
NRIV	51	52	80	103	114	99								
NRIVS	80	84	86	95	98									
NSS	222	224	225	227	166									
NX	155	156	161	163										
NX1	163	165												
NXMAX	26	155												
NXT1	165	178	179	221	235									

Symbol	References
NY	157 158 162 164 167 250 270 271 325 326 340 341 431
NY1	164 165 207 209 212 247
NYMAX	26 157
P	18 10
PA	18 9 26 57 145 197 198 248 270 271 325 326 340 341
PAA	18 9 434 342 199 205 281 340 351
PCN	18 10 87 201 272 207 129 134 128 270 281 340 351
PX	18 199 207 134 197 206 271 283 341 353
PXLX	18 129 91 135 131 135 198 200
PXS	18 88 207 130 135
PY	18 200 134 135 198 206 271 283 341 353
PYLY	18 131 207 134
PYS	18 131 135
ROBLK	44
RIV	18 86 94 96 97 100
S	18 26 66 67 74 75
SCORET	18 8 76
SDIV	18 29 134 74 76 87 88 90 91 128 130 139 145
SS	18 26 66 68 69 75 135
SUMX	18 63
SUMY	18 64
XOF	18 255 270
XOFS	18 9
YOF	18 256 271
YOFS	18 9

601	249	252					
620	95	98					
65	39	147					
650	96	100					
750	89	93	94	102			
760	104	113					
770	105	106	110				
780	114	116					
799	111	114					
800	83	117					
8030	43	46	50				
810	328	329					
820	361	365					
825	359	364					
830	356	366					
835	358	363	367				
845	343	347	350	352	354	356	364	369
850	331	336	338	346	370		
855	377	407					
858	379	381	383	386	395	400	
860	382	387					
862	389	393					
864	388	396	402				
865	387	401					
866	401	403					
868	380	408					
870	375	376	392	410			
880	423	425	429	441			
885	444	449					
890	448	458					
895	316	459					
898	314	318	460				
90	143	145					
905	469	475					
910	467	474	475	478			
915	468	479					
920	464	479	482	485			
925	491	524					
930	493	495	497	500	509	515	
935	496	501					
937	504	510					
940	503	507	519				
945	502	510					
946	511	517					
948	501	516					
950	516	519					

52	518	520					
60	489	490	494	506	525		
70	530	531	536				
90	243	537	539				
92	242	540					
RGS	10						
RRAY	8						
ATGP	11						
VMAT	0	360	377	535	719	1669	1695	1228
LOTAG	9						

APPENDIX II

NAME	PROGRAM VARIABLES - DESCRIPTION
ASFP	θ Scale Factor for Minutia Pairing Distance
COUNT(2500)	Registration X, Y Histogram
DELTH	$\triangle$ angle between rotations in Units of 1.40625 degrees each
DDX	Minutia X, Y tolerance values for neighborhood scoring
DELX	Minutia X, Y cell size for print registration
DX	Tolerance values for minutia pairing
DPX	X offset to exactly overlay a registered search minutia with its mating file minutia
DPY	Y offset to exactly overlay a registered search minutia with its mating file minutia
ERAA	Minutia Angle tolerance for print registration
ERAB	Minutia Angle tolerance for neighboring pairing
ERAM	Minutia angle tolerance for minutia pairing
F(612)	Sorted file minutia X, Y, θ values
HIT(1632)	Array of mating file and search minutia
IFLAG	Switch, if = 1, then search data is ready
IXMAX	Maximum X value of file minutia set
IXMIN	Minimum X value of file minutia set
IYMAX	Maximum Y value of file minutia set
IYMIN	Minimum Y value of file minutia set
ICXF	X Coordinate of minutia pattern center for file minutia set
ICYF	Y Coordinate of minutia pattern center for file minutia set
IANS	Maximum value of registration histogram
ISCORS	Match score for a given registration histogram maximum
ISCOR	Final match score (maximum of ISCORS values)

APPENDIX II (CONTINUED)

NAME	PROGRAM VARIABLES - DESCRIPTION
ASFP	θ Scale Factor for Minutia Pairing Distance
COUNT(2500)	Registration X, Y Histogram
DELTH	$\triangle$ angle between rotations in Units of 1.40625 degrees each
DDX	Minutia X, Y tolerance values for neighborhood scoring
DX	Minutia X, Y cell size for print registration, tolerance values for minutia pairing
DPX	X offset to exactly overlay a registered search minutia with its mating file minutia
DPY	Y offset to exactly overlay a registered search minutia with its mating file minutia
ERAA	Minutia Angle tolerance for print registration
ERAB	Minutia Angle Tolerance for Neighboring Pairing
ERAM	Minutia angle tolerance for minutia pairing
F(612)	Sorted file minutia X, Y θ values
HIT(1632)	Array of mating file and search minutia
IFLAG	Switch, if = 1, their search data is ready
IXMAX	Maximum X values file minutia set
IXMIN	Minimum X values file minutia set
IYMAX	Maximum Y values file minutia set
IYMIN	Minimum Y values file minutia set
ICXF	X Coordinate of minutia pattern center for file minutia set
ICYF	Y Coordinate of minutia pattern center for file minutia set
IANS	Maximum value of registration histogram
ISCORS	Match score for a given registration histogram maximum
ISCOR	Find match score (maximum of ISCORS values)

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APPENDIX II (CONTINUED)
PROGRAM VARIABLES - DESCRIPTION

NAME	
ISTAB	Array Containing Score Table
IJ	Pointer to PA array for best set of rotated search minutia
*IEOT	Early out threshold
IETP	Distance Tolerance for minutia pairing
ITSX	Scaled Variance of Matching Neighboring Minutia
ISCTVR(500)	Score Table
ISCORV	Individual Minutia Score
JXMIN	X Coordinate of Lower Left Corner of File Minutia Pattern
JYMIN	Y Coordinate of Lower Left Corner of File Minutia Pattern
JSCOR	Number of matching neighbors for a particular search minutia
KF(700)	Array of file minutia that are mated with search minutia
LX	1/2 width of effective file minutia pattern area
LY	1/2 height of effective file minutia pattern area
LAMIN	Maximum angle bias for search minutia angles
NHIT(48)	Array of file minutia mating with neighbors of a given search minutia
MMAX	Number of maximums in registration histograms
NB4	Number of neighbors to use times 4
NF	Number of file minutia
NMAX(5)	Array of best rotation for registration
NAT	Number of search print rotations to use
NF3	3 Times the number of file minutia
NRIV	Number of neighbors to use for neighborhood scoring
NP	Number of search minutia

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APPENDIX II (CONTINUED)

NAME   PROGRAM VARIABLES - DESCRIPTION

NBR(2040)   Neighbor array
NX   Count array size in X (Number of cells to use in count
              array in X direction)
NMM   Number of matching neighbors
NY   Count array size in Y (number of cells to use in count
              array in Y direction)
NP8   Number of search minutia times 8
NXMAX   Maximum number of count array cells in X direction
NYMIN   Maximum number of count array cells in Y direction
P(612)   Unsorted search minutia
PA(2040)   Rotated search minutia X, Y values
PAA(204)   Search minutia angle values
R40STB   Disk file containing score table
S(612)   Sorted Search Minutia
SS(612)   Sorted, Centered, Search Minutia
XOF   X offset to overlay search minutia on file minutia for
              registration histogram maximum
YOF   Y offset to overlay search minutia on file minutia for
              registration histogram maximum

I CLAIM

1. A method employing a programmed computer for comparing the minutiae
    of a search fingerprint (the "search minutiae") with the minutiae of
    a file fingerprint (the "file minutiae") to determine if the search
    fingerprint closely resembles the file fingerprint comprising:

    (a) rotating and translating the search minutiae to
        determine the rotation and translation which
        most nearly brings the search minutiae into
        registration with the file minutiae;

    (b) pairing mating search and file minutiae;

    (c) computing an individual minutia score for each search
        minutia that has a mating file minutia based on
        the spatial and angular relationship between the
        other mating file and search minutiae located
        within a neighborhood of each such search minutia;
        and

    (d) summing the individual minutia scores to obtain a
        final match score indicative of the overall resemblance
        of the search fingerprint to the file· fingerprint.

2. The method described in Claim 1 and further comprising:

    (a) sorting the search minutiae into angle order;

    (b) finding the closest neighbors for each search minutia;

    (c) sorting the file minutiae into angle order; and

    (d) computing maximum and minimum coordinates for the file
        minutia.

3. The method described in Claim 1 or 2 and further comprising terminating
    the comparison between the minutiae of a search fingerprint and the
    minutiae of a file fingerprint whenever the degree of registration
    of the search minutiae with the file minutiae fails to exceed an
    operator selected threshold.

4. A method employing a programmed computer for comparing the minutiae
    of a search fingerprint (the "search minutiae") with the minutiae
    of a file fingerprint (the "file minutiae") to determine if the
    search fingerprint closely resembles the file fingerprint comprising
    the following steps in the order named:

    (a) rotating and translating the search minutiae to determine
         the rotation and translation which most nearly brings
         the search minutiae into registration with the file
         minutiae;

    (b) pairing mating search and file minutiae;

    (c) computing an individual minutia score for each search
         minutia that has a mating file minutia based on the
         spatial and angular relationship between the other
         mating file and search minutiae located within a
         neighborhood of each search minutia; and

    (d) summing the individual minutia scores to obtain a final
         match score indicative of the overall resemblance
         of the search fingerprint to the file fingerprint.

5. The method described in Claim 4 and further comprising the following
    steps in the order named, and performed prior to the first step
    described in Claim 1:

    (a) sorting the search minutiae into angle order;

    (b) finding the closest neighbors for each search minutia;

    (c) sorting the file minutiae into angle order; and

    (d) computing maximum and minimum coordinates for the file
         minutia.

6. The method described in Claim 4 and further comprising the
    following step performed between steps (b) and (c) of Claim 4:
    terminating the comparison between the minutiae of a search fingerprint
    and the minutiae of a file fingerprint whenever the degree of
    registration of the search minutiae with the file minutiae fails to
    exceed an operator selected threshold.

7. The method described in Claim 5 or 6 wherein the step of rotating
    and translating the search minutiae to determine the rotation and
    translation which most nearly brings the search minutiae into
    registration with the file minutiae comprises:

    (a) rotating the search minutiae through a preselected
         set of rotations;

    (b) for each rotated set of search minutia constructing
         a histogram showing the number of coincident search
         and file minutiae for various translations of the
         search minutiae relative to the file minutiae; and

    (c) determining the rotation and translation to which most
         nearly brings the search minutia into registration with
         the file minutiae by comparing the magnitudes of the
         largest adjacent blocks of entires in each of the
   histograms.

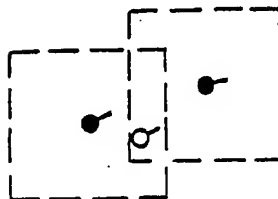8.　A device for comparing the minutiae of a search fingerprint
　　(the "search minutiae") with the minutiae of a file fingerprint
　　(the "file minutiae") to determine if the search fingerprint
　　closely resembles the file fingerprint comprising:

　　　　(a)　rotating and translating means for rotating and
　　　　　　　translating the search minutiae to determine the
　　　　　　　rotation and translation which most nearly brings
　　　　　　　the search minutiae into registration with the
　　　　　　　file minutiae;

　　　　(b)　pairing means for pairing mating rotated and translated
　　　　　　　search and file minutiae;

　　　　(c)　scoring means for computing an individual minutia
　　　　　　　score for each search minutia that has a mating
　　　　　　　file minutia based on the spatial and angular
　　　　　　　relationship between the other mating file and
　　　　　　　search minutiae located within a neighborhood of
　　　　　　　each such search minutia; and

　　　　(d)　summing means for summing the individual minutia
　　　　　　　scores to obtain a final match score indicative of
　　　　　　　the overall resemblance of the search fingerprint
　　　　　　　to the file fingerprint.

9.　The device described in Claim 8 and further comprising:

　　　　(a)　first sorting means for sorting the search minutiae
　　　　　　　into angle order;

　　　　(b)　finding means for finding the closest neighbors for
　　　　　　　each search minutia;

　　　　(c)　second sorting means for sorting the file
　　　　　　　minutiae into angle order; and

　　　　(d)　coordinate means for computing maximum and minimum
　　　　　　　coordinates for the file minutia.

10. The device described in Claim 8 or 9 and further comprising terminating means for terminating the comparison between the minutiae of a search fingerprint and the minutiae of a file fingerprint whenever the degree of registration of the search minutiae with the file minutiae fails to exceed an operator selected threshold.

11. The device described in Claim 8 or 9 wherein the rotating and translating means for rotating and translating the search minutiae to determine the rotation and translation which most nearly brings the search minutiae into registration with the file minutiae comprises:

      (a)   rotating means for rotating the search minutiae through a preselected set of rotations;

      (b)   for each rotated set of search minutiae constructing means for constructing a histogram showing the number of coincident search and file minutiae for various translations of the search minutiae relative to the file minutiae; and

      (c)   determining means for determining the rotation and translation which most nearly brings the search minutiae into registration with the file minutiae by comparing the magnitudes of the largest adjacent blocks of entries in each of the histograms.

FIG.1A

SEARCH MINUTIA

FIG.1B

FILE MINUTIA

FIG.1C

SEARCH MINUTIA SUPERIMPOSED ON FILE MINUTIA
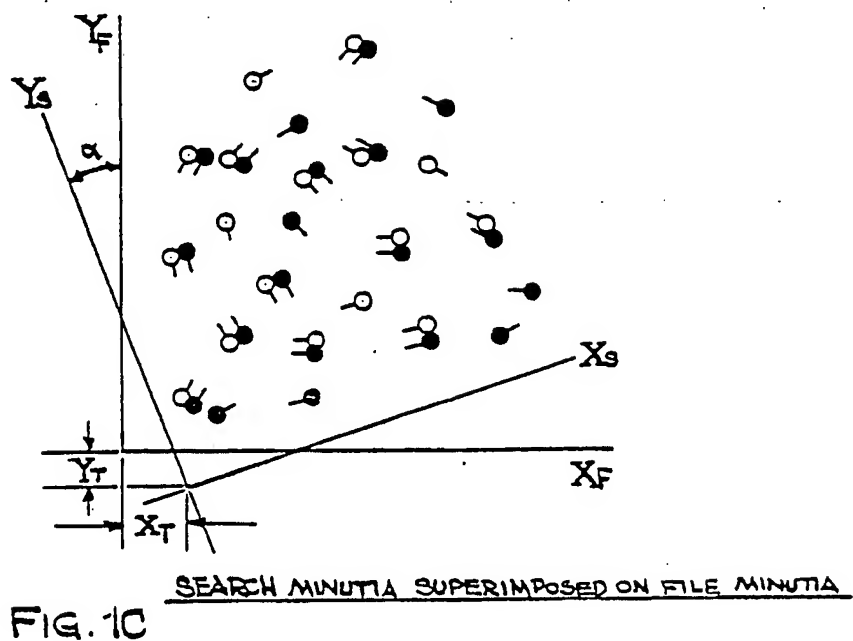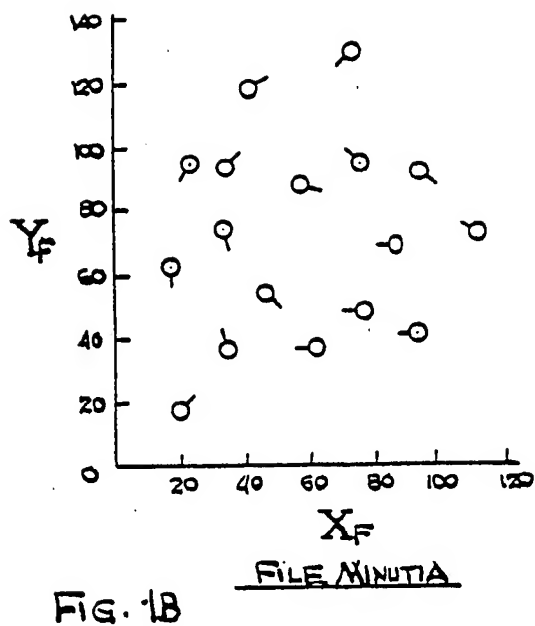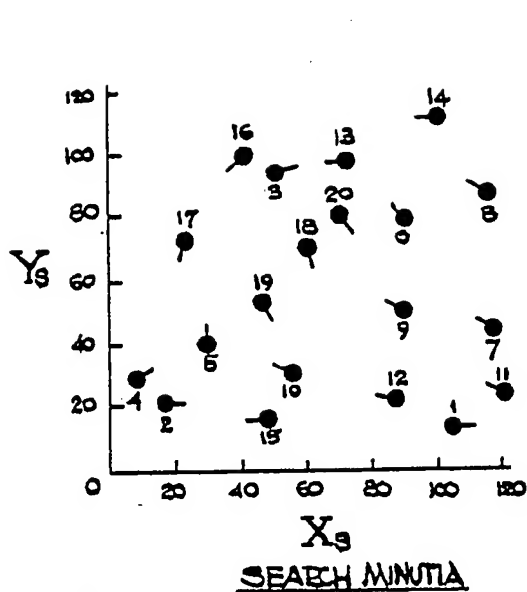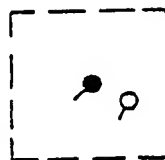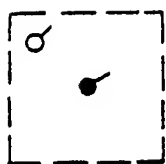
MATING
MINUTIA PAIRS

FIG. 2A
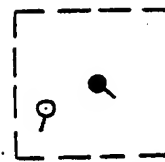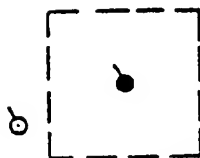
NON-MATING
MINUTIA PAIRS

(ANGLE DIFFERENCE
TOO LARGE)

FIG. 2B
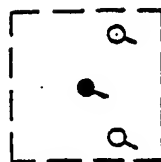
MULTIPLE MATING
POSSIBILITIES

FIG. 2C

Y_S

X_S
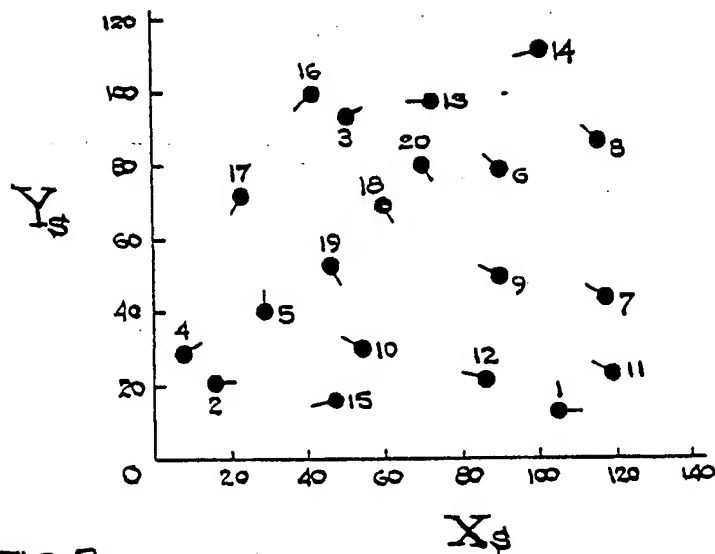
FIG. 3

SEARCH MINUTIA PATTERN

TRANSLATION EQUATIONS:

$$\triangle X = X_S - X_F + 2$$

$$\triangle Y = Y_S - Y_F$$

FIG. 4A

FILE PRINT MINUTIA PATTERN

FIG. 4B

FIG. 7

Fig. 5

START ───────────────►┌──────────────────────────────────┐
                      │ LIST, FOR EACH SEARCH MINUTIA, IN │
                      │ ASCENDING ORDER OF CLOSENESS, ALL │
                      │ FILE MINUTIA WHICH ARE CLOSE TO IT.│
                      └──────────────────────────────────┘

┌──────────────────────────────────┐
│ GET NEXT MINUTIA PAIRING FROM LIST.│
│ OVERLAY SEARCH MINUTIA ON FILE   │
│ MINUTIA.   │
└──────────────────────────────────┘

┌──────────────────────────────────┐
│ FORM NHIT LIST GIVING FILE MINUTIA │
│ WHICH ARE "CLOSE" TO NEIGHBORING   │
│ SEARCH MINUTIA. ORDER ON   │
│ ASCENDING VALUES OF CLOSENESS.   │
└──────────────────────────────────┘

┌──────────────────────────────────┐
│ ELIMINATE DUPLICATE FILE MINUTIA   │
│ FROM NHIT LIST BY MAXIMIZING FIRST,│
│ NO. OF NEIGHBORS HAVING MATING   │
│ FILE MINUTIA, AND SECOND, CLOSENESS│
│ OF MINUTIA PAIRS.   │
└──────────────────────────────────┘

┌──────────────────────────────────┐
│ FIND SCORE FOR THIS MINUTIA PAIR   │
│ BASED ON NUMBER OF MATING   │
│ NEIGHBORS AND VARIANCE OF FIT.   │
│ ENTER THE SCORE INTO THE HIT LIST │
│ IN PLACE OF CLOSENESS MEASURE.   │
└──────────────────────────────────┘

YES ┌──────────────────────────────────┐
    │ MORE ENTRIES IN INITIAL HIT LIST? │
    └──────────────────────────────────┘
                    NO

┌──────────────────────────────────┐
│ ORDER HIT ARRAY ENTRIES FOR EACH   │
│ SEARCH MINUTIA BASED ON SCORE.   │
└──────────────────────────────────┘

┌──────────────────────────────────┐
│ CONSIDERING ONLY THE FIRST TWO   │
│ FILE ENTRIES FOR EACH SEARCH   │
│ MINUTIA IN THE HIT LIST, ELIMINATE │
│ DUPLICATE FILE MINUTIA BASED ON   │
│ MAXIMIZING TOTAL MATCH SCORE AS   │
│ DETERMINED ON A "TWO-PAIR" BASIS. │
└──────────────────────────────────┘

┌──────────────────────────────────┐
│ SUM INDIVIDUAL SEARCH MINUTIA   │────► RETURN
│ SCORES TO GET TOTAL MATCH   │
│ SCORE.   │
└──────────────────────────────────┘

FIG. 6

FIG.8

BUREAU
OMPI
WIPO

FIG. 9
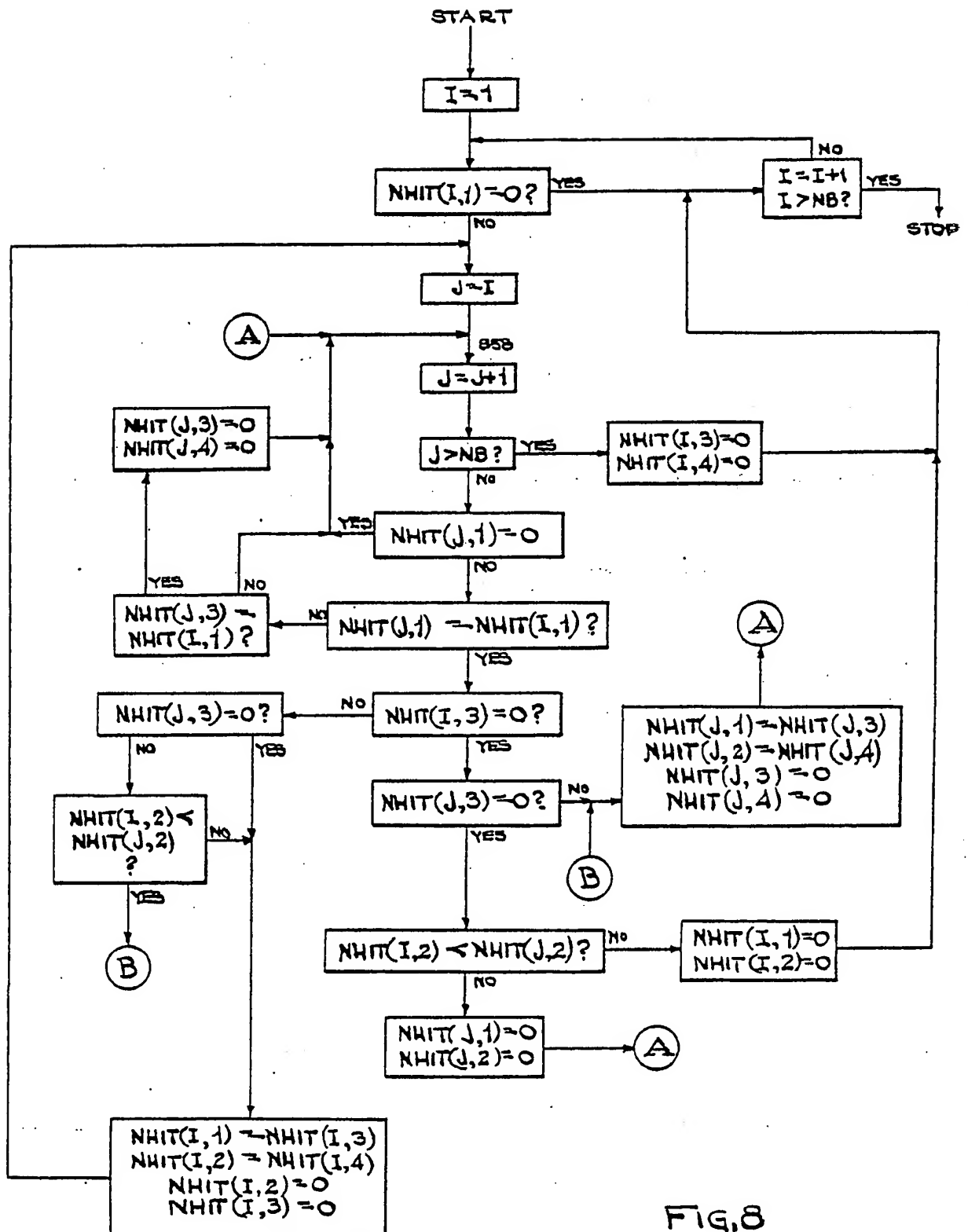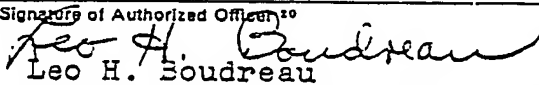
INTERNATIONAL SEARCH REPORT

International Application No PCT/US81/01412

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all) ³

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl.³ G 06K 9/68
U.S. Cl. 340/146.3 E

II. FIELDS SEARCHED

Minimum Documentation Searched ⁴	
Classification System	Classification Symbols
U.S.	340/146.3 E, Q, AQ 340/825.3, 825.31, 825.33, 825.34 356/71

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched ⁵

III. DOCUMENTS CONSIDERED TO BE RELEVANT ¹⁴

Category *	Citation of Document, ¹⁶ with indication, where appropriate, of the relevant passages ¹⁷	Relevant to Claim No. ¹⁸
A	US, A, 4,210,899, Published 1 July 1980, Swonger et al.	1-11
A	US, A, 4,047,154, Published 6 September 1977, Vitols et al.	1-11
X	US, A, 4,185,270, Published 22 January 1980, Fischer II et al.	1, 3-4, 6, 9, 10
X	US, A, 3,638,188, Published 25 January 1972, Pincoffs et al.	1-11
X	US, A, 3,292,149, Published 13 December 1966, Bourne.	1-11

* Special categories of cited documents: ¹⁵

"A" document defining the general state of the art

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"L" document cited for special reason other than those referred to in the other categories

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"P" document published prior to the international filing date but on or after the priority date claimed

"T" later document published on or after the international filing date or priority date and not in conflict with the application, but cited to understand the principle or theory underlying the invention

"X" document of particular relevance

IV. CERTIFICATION

Date of the Actual Completion of the International Search ²	Date of Mailing of this International Search Report ²
19 January 1982	22 JAN 1982
International Searching Authority ¹	Signature of Authorized Officer ²⁰
ISA/US	Leo H. Boudreau

Form PCT/ISA/210 (second sheet) (October 1977)

BAD ORIGINAL